This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

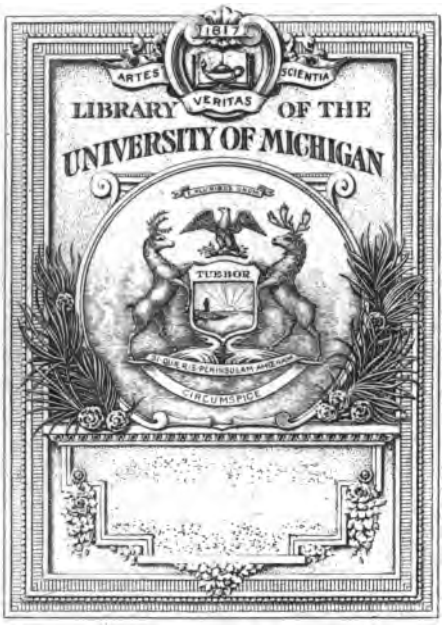
About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

TN
297
.G78

B 475242

Digitized by Google


1817
ARTES
SCIENTIA
VERITAS
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
CIRCUMSPICE

Google

TN
297
.G78

Digitized by Google

Digitized by Google

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

ADVISORY COUNCIL.

SECOND REPORT

OF THE

MINE RESCUE APPARATUS RESEARCH COMMITTEE.

Digitized by Google

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

LIST OF OFFICIAL PUBLICATIONS

The publications named below can be purchased through any bookseller or direct from

H.M. STATIONERY OFFICE at the following addresses:

Imperial House, Kingsway, London, W.C.2, and
28, Abingdon Street, London, S.W.1
37, Peter Street, Manchester;
1, St. Andrew's Crescent, Cardiff;
80, Chichester Street, Belfast;
or from E. PONSONBY, Ltd., 116, Grafton Street, Dublin.

The offices of the Department are unable to supply these direct.

Remittances should be made payable to the Stationery Office at the above addresses. Applications by post to the Stationery Office should quote the description and price of the publications required, and should be accompanied by the cash or coupons specified in the list.

ANNUAL REPORTS OF THE DEPARTMENT.

Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1916–17. (Cd. 8880.) Price 3*d.* (by post 4*d.*).

Ditto ditto 1917–18. (Cd. 9171.) Price 4*d.* (by post 6*d.*).

Ditto ditto 1917–18. (Cd. 9144.) Price 1*d.* (by post 2*d.*).

Ditto ditto 1918–19. (Cmd. 389.) Price 6*d.* (by post 8*d.*).

Ditto ditto 1919–20. (Cmd. 985.) Price 1*s.* (by post 1*s.* 2*d.*).

FUEL RESEARCH BOARD.

Report of the Fuel Research Board on their Scheme of Research and on the Establishment of a Fuel Research Station. 1917. Price 2*d.* (by post 3*d.*).

Report of the Fuel Research Board for the years 1919 and 1920. (Cmd. 1116.) Price 1*s.* 6*d.* (by post 1*s.* 9*d.*).

SPECIAL REPORT SERIES:—

No. 1. Report on Pulverised Coal Firing in Yorkshire Re-Heating & Heating Furnaces and the Production of Low Grade Producer Gas. 1918. Price 2*s.* net (by post 2*s.* 3*d.*).

No. 2. The Peat Resources of Ireland. By Professor Dr. John T. Purser, M.Inst.C.E. 1*d.* Price 9*s.* net (by post 11*s.*).

No. 3. "The Coal Fire." By Margaret White Fishenden. Price 1*s.* (by post 1*s.* 2*d.*).

Digitized by Google

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

ADVISORY COUNCIL.

SECOND REPORT

OF THE

MINE RESCUE APPARATUS RESEARCH COMMITTEE.

LONDON:
Printed and Published for the Department of Scientific and Industrial Research by His Majesty's Stationery Office.
1920.

(*Reprinted* 1921.)

Price 2*s.* 0*d. Net.*

Digitized by Google

Digitized by Google

Brit. Surg. Lib.
6-23-31
3929

PREFATORY NOTE.

The Mine Rescue Apparatus Research Committee, whose First Report was published in 1918, was appointed by the Advisory Council for Scientific and Industrial Research, on the suggestion of the Home Office, in 1917, and consists of:—

Mr. William Walker, C.B.E., Chief Inspector of Mines (*Chairman*).
Mr. Henry Briggs, O.B.E., D.Sc., A.R.S.M., M.I.M.E.
Mr. John Haldane, M.D., LL.D., F.R.S.

Dr. Briggs, as heretofore, has continued to direct the experimental work of the Research at the Heriot-Watt College, where facilities are provided by the kindness of the Governors of the Heriot Trust.

This Second Report of the Committee is published with the concurrence of the Home Office.

Department of Scientific and Industrial Research,
16 and 18, Old Queen Street, Westminster, S.W.1.

June, 1920.

(32198) Wt. 35327—781 750 3/21 H. St. G. 2

Digitized by Google.

LIST OF ILLUSTRATIONS.

Fig. 1. Proto bag with Cooling Compartment.
,, 2. Drier for use with Oxygen Pump.
,, 3. Apparatus for ascertaining slip of valves.
,, 4. Tissot Mouthpiece.
,, 5. Split-tube Valve (two views).
,, 6. Rosling Valve (two views).
,, 7. Mueller Water Valve.
,, 8. Spring Nose-clip used at Swansea.
,, 9. German form of Screw Nose-clip.
,, 10. Hopwood's Spring Nose-clip.
,, 11. Flow-meter for Proto Apparatus.
,, 12. The Flow-meter in position, Proto Apparatus.
,, 13. Haldane's Equilizing Arrangement and Air Tube.
,, 14. Briggs' Equilizing Arrangement and Air Tube.
,, 15. Electric Head Lamp in use.
,, 16. Briggs Compressed Oxygen Rescue Apparatus.
,, 17. Briggs Rescue Apparatus, flow diagram.
,, 18. Sunk-spindle Cylinder Valve, Briggs Apparatus.
,, 19. Key for Sunk-spindle Valve.
,, 20. Oxygen Feed Gear and Gauges, Briggs Apparatus.
,, 21. Fluted Gauze for Purifier, Briggs Apparatus.
,, 22. Die for stamping Gauze Trays, Briggs Apparatus.
,, 23. Method of Insulating Purifier, Briggs Apparatus.
Figs. 24 & 25. Expiratory and Inspiratory Valve, Briggs Apparatus.
Fig. 26. Relief Valve, Briggs Apparatus.
,, 27. Mouthpiece and Saliva Trap, Briggs Apparatus.
,, 28. Position of teeth when using ordinary mouthpiece.
,, 29. Position of teeth when using mouthpiece of Briggs Apparatus.
,, 30. Testing with the Ergometer, Physical Test Station, Edinburgh.
Figs. 31–37. Graph-records of various subjects: Ergometer Testing.

Digitized by Google

MINE RESCUE APPARATUS RESEARCH COMMITTEE.

SECOND REPORT.

INTRODUCTION.

To the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research.

Gentlemen,

We beg to submit our Second Report. It relates chiefly to experimental results obtained in Edinburgh during the last two years, and to the description of new or improved methods and apparatus which are the outcome of the investigation.

By the terms of reference we are required to state whether we deem it advisable that the types of mine rescue apparatus should be standardised. We do not think that standardisation, in the sense of a prescribed uniformity of construction, is to be recommended in this instance. We prefer that the field for invention and enquiry should be left open rather than be circumscribed by a hard-and-fast specification. On the other hand (as we stated in the First Report), we hold that every type of breathing apparatus intended for use in mines should be tested very thoroughly before being officially approved for that purpose, and we consider that the manner of testing should be standardised. Building upon the general requirements of such apparatus, as set forth in our previous Report, we have drawn up a scheme of examination which we think could with advantage be adopted for testing an apparatus. The American Bureau of Mines has recently formulated a somewhat similar scheme of examination; we are indebted to the Director for kindly providing a copy of that document, which has been useful to us in drafting our own scheme. It is interesting that in respect of these apparatus the two countries should be progressing on lines so closely alike.

The requirements of our First Report (pp. 14 to 17) are very comprehensive. To avoid the criticism that our recommendations amount to a counsel of perfection, and also to carry out in the fullest sense that part of the terms of reference which gives us the task of determining by experiment what improvements in apparatus are possible, it became incumbent upon us to prove that it was feasible to devise a compressed-oxygen rescue apparatus complying with those requirements; the construction of such an apparatus was, therefore, given the leading place in the programme of work for the present financial year. In this Report we include, in Appendix I, drawings and a description of the compressed oxygen apparatus designed by Dr. Briggs, and an account of the tests to which the first model has been subjected. No claim of finality is made on behalf of this apparatus; it embodies several points of design in existing apparatus and will itself doubtless be improved in the light of further experience.

Down to the time of writing we have given much less attention to liquid air rescue apparatus than to those depending on compressed oxygen. There are two reasons for postponing work on the former type: first, as conditions now stand, there are over seventeen times as many compressed oxygen as liquid air apparatus in use in this country, and the type in greater vogue must naturally take precedence; secondly, our suggestion that a separate research committee be set up to investigate the problems of the supply and transport of liquid and gaseous oxygen was adopted by you, with the result that the Oxygen Research Committee was established in 1918, first under the auspices of the War Priorities Committee

and now under the Department of Scientific and Industrial Research—which Research Committee is actively considering many questions bearing on the utilisation of liquefied air and oxygen. As so much of the work of the Oxygen Research Committee, and of the War Office and Air Ministry, on the subject of liquid air is bound to be of the greatest value to us, we deemed it politic to allow these more general investigations time to mature before attempting to experiment systematically on the narrower problem of liquid air rescue apparatus. Experience has, however, shown that, apart from certain difficulties of transport, this type of apparatus can be made thoroughly serviceable, and we propose to devote further attention to it in the near future.

The present Report consists of four parts. In the first of these the physiological side of the subject is discussed more completely than hitherto, and an abbreviated account is included of some important new physiological facts which were discovered in the course of the experiments. In Parts II-IV we deal mainly with matters alluded to in the First Report, the need having arisen, as the result of special experience or experiment, of re-treating or enlarging upon certain aspects of the inquiry. Appendix II, by Dr. Briggs, describes a method of measuring physical fitness which evolved, during 1918, from tests on trained rescue men in Edinburgh. A Physical Test Station was established in Edinburgh to apply this method in testing the physical capabilities of recruits and others sent in from Army Units stationed in that military area. The Test Station was in the University buildings, and had a small military staff under Dr. Briggs' superintendence; it commenced operations in August, 1918, and ceased its active life at the Armistice, in November. Although an outcome of the research on Mine Rescue Apparatus, an exhaustive account of the experiments on physical exertion and of the work of the Test Station would be out of place in such a Report as this; with your permission, it is, therefore, proposed that Dr. Briggs should immediately prepare a paper for the Royal Society of Edinburgh in which to treat of the matter more completely. A short preliminary paper by Dr. Briggs, entitled "Fitness and Breathing during Exertion," was read before the Physiological Society in July, 1919.

In the autumn of 1918, Lieut.-Colonel Raper, of the Anti-Gas Department, Ministry of Munitions, proposed that there should be a closer connection between his Department and the research, and offered to appoint Lieutenant Rosling as liaison officer. We cordially welcomed that proposal, and take this opportunity of thanking the Anti-Gas Department for Lieutenant Rosling's services, which have been of decided value to us since he was transferred to Edinburgh. We refer again, on a later page, to the connection between the two investigations.

Miss Elizabeth Gilchrist, M.A., B.Sc., and Mr. David Penman, B.Sc., who assisted Dr. Briggs since July, 1917, have recently accepted other posts; the former as Carnegie Research Fellow in the University of Edinburgh and the latter as Lecturer in Mining in the St. Helen's Technical Institute. We are sorry to lose the help of these expert assistants, who gave two years of loyal work to the research. In September, 1918, Mr. Penman read an excellent digest of the First Report before the Institution of Mining Engineers, and the ensuing discussion was of much value.

Mr. F. J. McConnell has been elected in Mr. Penman's place.

We are also sorry to lose the valuable services of Mr. A. Richardson, who has been appointed Principal of the School of Metalliferous Mining, Cornwall. Mr. E. Barnard takes Mr. Richardson's post as Secretary to the Committee.

We are indebted to Mr. James A. Hood, Mr. Mungo Mackay, and other officials of the Lothian Coal Company for their kindly help in carrying out underground respiration experiments, and to a large number of mine and rescue station officials, miners, army officers and men who so willingly acted as subjects in tests which were often of an exacting description.

We have again to record our appreciation of the valuable assistance rendered the Governors of George Heriot's Trust in granting facilities for the research the Heriot-Watt College, Edinburgh.

Digitized by Google

PART I.

PHYSIOLOGICAL CONSIDERATIONS AND EXPERIMENTS.

Physiology stands in much the same relation to breathing apparatus as physics does to the steam engine; and a condensed statement of the physiology of breathing and its accompanying effects and reactions is, we think, as necessary here as the treatment of thermodynamics in a modern book on steam. Several of the defects of existing rescue apparatus alluded to in our First Report are due to a disregard, or false appreciation, of certain physiological laws, which, when thoroughly grasped, are capable of materially assisting the designer of such apparatus.

The ventilation of the lungs by breathing has a dual purpose: it supplies oxygen to the blood and removes excess of carbon dioxide from it. The blood, in its turn, carries oxygen to all parts of the system, and conveys back to the lungs the carbon dioxide, which is the chief (though not the only) waste product of that breaking-down of tissue which goes on as long as life lasts. The muscular contractions, which enable us to do external work in giving potential or kinetic energy to ourselves or to some separate body, involve an increase in tissue destruction, which results in a demand for a more energetic clearance of the CO_2 produced and for an enhanced oxygen intake. Unless the exertion is excessive or the oxygen supply inadequate—cases which are separately considered below—the demand is fully met by the lungs of a healthy person in increased breathing and by the heart in increased blood-circulation.

Normal Respiratory Control.—The spongy distensible organs we call the lungs consist of a branching system of tubes (bronchi) ending in air sacs (alveoli) which are surrounded by a cellular membrane (epithelium). Breathing causes an alternating flow of air in the bronchi and so ventilates the air sacs; on inspiration, oxygen is carried into them; on expiration, carbon dioxide is carried out. The epithelium separates the air in the alveoli and the blood which courses in countless capillaries on the inner side of that membrane. The gaseous exchange—oxygen to the blood and CO_2 from it—is thus conducted through the epithelium.

Haldane and Priestley* showed that, in normal conditions near sea-level and with the subject at rest, the respiration is so adjusted as to keep constant the CO_2 percentage in the alveolar air at a figure which varies with different individuals, but which averages 5·6 for men.

It is important to realise the fact that *under normal conditions*, when resting, the factor controlling breathing is the concentration of CO_2 in the blood. The part of the brain known as the "respiratory centre," which directs the movements of the lungs, receives its incentive from the CO_2-saturation of the blood passing through it, and it controls matters (with an almost inconceivably delicate degree of regulation) so as to maintain that saturation at a constant level. If the blood should become over-concentrated in CO_2, enhanced breathing (hyperpnœa) results, and continues until the excess is removed; if for any reason the degree of saturation is reduced below normal, there is a cessation of breathing (apnœa) until the deficiency disappears. "The respiratory centre must evidently be regarded as a very sensitive governor of the CO_2 pressure in its own substance, and indirectly in the arterial blood and alveolar air. We may compare its action to that of the governor of an engine, if we may bear in mind that the respiratory centre governs CO_2 percentage, whereas the governor of the engine controls its rate of revolution."†

The fact that CO_2, and not oxygen, normally dominates the respiratory centre was strikingly illustrated in a famous experiment of Professor Yandell Henderson. He subjected an animal to prolonged artificial respiration, so as to swill out most of the CO_2 in solution in the blood. When the animal was left to itself, apnœa was so profound that it died of want of oxygen before breathing recommenced.

---

* Journal of Physiology, XXXII, p. 225, 1905.

† Haldane and Priestley, "The Regulation of Normal Breathing." Journ. of Phys., XXXVIII, 1909, p. 420.

Digitized by Google

Extended study of this problem of breathing control reveals that other acid compounds as well as CO_2 are able to stimulate the respiration when introduced into the blood—a principle to which we shall recur in discussing the meaning of certain experimental results.

Nearly all the carbon dioxide is conveyed by the blood as unstable bi-carbonates, and passes through the epithelium into the alveoli. The hæmoglobin (red pigment) is the main oxygen carrier of the blood. In small quantities both nitrogen and oxygen are taken up in ordinary solution, but when breathing normal air at normal pressure, the amount of oxygen borne in this way is, as a source of supply, of little account. Hæmoglobin enters into a definite, though unstable, chemical union with the oxygen, and it is as "oxyhæmoglobin" that oxygen is mainly carried by the blood. If the active hæmoglobin is reduced in amount, say by breathing air containing carbon monoxide, collapse, loss of consciousness or death may ensue from oxygen starvation.

Effects of Breathing Air rich in Oxygen.—When a man wears a rescue apparatus the percentage of oxygen in the apparatus may easily rise over 90. The influence on his ability to undertake physical work when breathing air enriched to such a degree has been studied by us with some care, and on a later page a short account is given of the results obtained. Two other effects fall to be noted at this place:—The first of these is due to the high partial pressure* of oxygen in the air inhaled, which brings about an increase in the proportion of oxygen carried in ordinary solution by the blood as distinct from that carried in chemical combination by the hæmoglobin. The bearing of this effect in retarding the consequences of inhaling CO, and in explaining the efficacy of administering oxygen to a person suffering from CO poisoning, has already been dealt with in the First Report, p. 16.

Discharge of Nitrogen from the Blood.—The second is that, simultaneously with the taking up of oxygen in solution, there is a discharge of nitrogen from the blood, since the partial pressure of nitrogen in the alveolar air is greatly reduced. Thus we have in the blood itself an additional source of nitrogen. In the closed circuit of a rescue apparatus, the nitrogen so expelled remains in the apparatus unless voided through the relief valve. As blood-nitrogen is only discharged when the oxygen percentage is increasing in the inhaled air, and as it is limited in volume, it does not contribute in any way to the risks of using rescue apparatus. Indeed, providing that a start is made with the apparatus full of oxygen and that the further precaution is taken of swilling it out now and then with the by-pass, the expulsion of the blood-nitrogen makes slightly for safety; for should the oxygen proportion in the inhaled air sink at any subsequent time, the blood will remove some of the accumulating nitrogen by re-solution.

Fallacious Views as to Effects of Breathing Oxygen.—The entirely incorrect view that oxygen is a "dope," and that the breathing of highly enriched air results in a rapid burning up of the tissues accompanied by excitement and violent bursts of physical energy, or that it is followed by depression and lassitude, is still held by many people. We find the fallacy to persist even among rescue station instructors, and we cannot regard without misgiving its influence on their method of using breathing apparatus. Purposely to retain nitrogen in the bag in order to prevent the wearer getting "too much oxygen" is to run grave risks (*see* First Report, pp. 20 and 26). One of the difficulties encountered in introducing oxygen apparatus for high-altitude aeroplane flying is the antipathy of many airmen to what they consider to be the drug-like properties of the gas. It ought not to be necessary to state to those habitually using rescue apparatus that there is not the least evil effect or objection of any kind attending the breathing of pure or almost pure oxygen even for several hours, and that the alleged consequences referred to above are altogether fictitious. On the contrary, fatigue is appreciably lessened by oxygen inhalation as will be shown below.

* In air containing 21% of oxygen, the partial pressure of that gas is 0·21 of an atmosphere or 159 mm. of mercury. In air containing 90% the partial pressure is 0·90 of an atmosphere or 84 mm. of mercury.

Digitized by Google

It is only when air containing over 80 per cent. oxygen is breathed continuously for over two days that evil effects make themselves felt. Professor Lorrain Smith was the first to show that inflammation of the lungs may be produced in animals if they are kept in such an atmosphere for at least two days.

Transference of Oxygen from the Air to the Blood.—We have yet to refer to the manner in which the oxygen reaches the blood through the epithelium. The physical laws of diffusion do not explain the phenomena of blood-oxygenation when the subject is making a special demand on oxygen supply either because he is doing physical work or because, as airman or mountaineer, he is breathing rarefied air. The results obtained in 1911 during a month's sojourn on the summit of Pike's Peak, Colorado, (14,000 ft.)* may usefully be mentioned. They made it clear that the system is able to adapt itself to the lowered pressure, so that it can obtain, without distress, a sufficiency of oxygen. It was found that, to secure the necessary supply, the pressure of oxygen in the arterial blood rose higher than the partial pressure of oxygen in the atmosphere—a state of affairs which cannot be explained on the assumption that the oxygen input to the blood is altogether the result of gaseous diffusion. Though admittedly standing now on controversial ground, the evidence strongly supports the view that the epithelium is not a mere porous diaphragm, but that the living cells from which it is built possess the faculty—which they exercise at need—of secreting oxygen from the air and of handing it forward at enhanced pressure to the blood. There seems, indeed, little doubt that this attribute of *secretion* can be developed or improved (especially in a young person) by physical training or by adaptation to low oxygen pressure.

Effects of Oxygen-want and CO_2-excess on Breathing.—It has been proved that, when a person is caused to breathe air containing several parts per cent. of CO_2, an increase in the depth of breathing results, though the rate may remain constant until the CO_2 mounts up still higher.

In considering the influence of oxygen-want care must be taken to distinguish between the effect of breathing air having a reduced oxygen percentage and that resulting from fatigue. As will be shown below, respiratory fatigue produced, *e.g.*, by respiring against resistance, creates a type of breathing which develops oxygen-want; at this point, however, we consider the simpler case in which the lack of oxygen is produced solely by deficiency of oxygen in the inspired air.

When a man begins to breathe air poor in oxygen, the response of the respiratory control differs according to the degree of oxygen-want. If the latter be slight, "periodic breathing" often sets in, this being characterised by the breathing becoming excessive and dying away in alternating succession. If the lack of oxygen be more pronounced, the breathing is fairly regular but more rapid, though much less deep than when it is stimulated by CO_2.

From the point of view of the user of breathing apparatus, it is enough to remember that excess of CO_2 induces deep and slow, and oxygen-want quick and rather shallow, breathing.

Shortage of oxygen takes effect much more quickly than CO_2 excess, since the body has practically no storage capacity for oxygen while it has a great deal for carbon dioxide.

The Effects of Breathing against Resistance.—In the First Report (p. 17) we referred to the causes and to the physical results of excessive resistance in the breathing circuit of a rescue apparatus, in regard both to the enhanced risk of leakage and to the discomfort of the wearer. We now propose to consider briefly the physiological effects of resistance. The subject has recently been investigated by Davies, Haldane and Priestley.†

When a resistance to breathing is thrown in, the first effect is that the breathing movements are slowed. As a consequence of this CO_2 begins to accumulate to

---

* *Physiological Observations made on Pike's Peak, Colorado, with special reference to adaptation to Low Barometric Pressures*, by C. G. Douglas, J. S. Haldane, Y. Henderson, and E. C Schneider, Phil. Trans. vol. 203, p. 185.

† *Journ. of Physiol.*, LII, 1919.

Digitized by Google

an abnormal extent in the lungs, and consequently in the arterial blood. A very slight accumulation, however, suffices to make the breathing more energetic and deeper, so that as much air is breathed as before, though the frequency of breathing is diminished and the depth correspondingly increased. In this way moderate resistances are easily compensated for automatically, even during the greatly increased breathing which accompanies muscular exertion.

When, however, the resistance is heavy, the excess of CO_2 which is required in the lung air in order to stimulate the breathing sufficiently becomes very marked, and finally fatigue of the breathing begins to show itself through the fact that the breathing becomes more and more frequent and shallow. With the increasing shallowness the penetration of fresh air into the lungs becomes less and less effective; and unless relief comes symptoms of asphyxia develop.

As might be expected, fatigue of breathing occurs much more readily during muscular exertion, when a large amount of air has to be breathed, than during rest. In consequence of this fact continued muscular exertion may easily be rendered impossible by undue resistance to breathing. It must also be borne in mind that when resistance is due to tubes, valves, or passage of air through coarsely divided material, the resistance increases as the square of the rate of air-flow. It is, therefore, the resistance to air-flow during muscular exertion that needs special attention in connection with mine rescue apparatus. This resistance ought to be so low that, even during prolonged exertion, symptoms of fatigue of breathing do not appear. There is no need to try to abolish resistance entirely, but only such resistance as will materially hamper a man's power of making such exertions as he may be called on to make continuously while using a mine rescue apparatus. We think that the exertion of walking continuously at the rate of four miles per hour may be taken as a standard test in this respect.

A man who is in poor physical training develops respiratory fatigue much more easily than a man in good training. This appears to be due largely to the fact that in the former, as shown in another section of this Report, the absorption of oxygen by the lungs during exertion is less perfect, and that any shortage of oxygen in the blood precipitates respiratory fatigue, as is proved in the paper first referred to. In the case of a man wearing a mine rescue apparatus and breathing nearly pure oxygen, this cause of respiratory fatigue is, however, annulled, so that with the same amount of work the man in poor training develops less respiratory fatigue when he is wearing the apparatus than when he is breathing ordinary air.

In different individuals the susceptibility to respiratory fatigue from resistance varies considerably, some persons being able to stand much greater resistance than others. Some, indeed, appear to be quite exceptionally sensitive to resistance. For this reason it is impossible to state for all persons the amount of resistance which is harmful, though, at a later page (p. 22), we have suggested a figure (*viz.*, 3 ins. of water gauge under a constant rate of flow of 85 litres of air per minute) as the limiting resistance of a rescue apparatus circuit. With most people such a degree of resistance is not detrimental, and if, during the walking test with an apparatus complying with that specification, any man is found to be so sensitive that he shows signs of respiratory fatigue, we think that he ought not to be accepted as a member of a rescue team. This criterion would automatically exclude many older men.

Physical Exertion.—The requirements and limitations of what is often called the human machine are of such importance to those dealing with rescue apparatus that it becomes as necessary to study the man in his character of prime mover or agent for doing mechanical work as to study the apparatus itself, and we have devoted considerable time to this aspect of the subject.

Oxygen Supply to Muscles at Work.—The all-important question of oxygen supply to the tissues is controlled by two factors, namely, the rate at which the gas can be absorbed by the blood in the lungs and the rate at which the oxygenated blood can be delivered to the muscles doing work. The supply can only be effectual when the lungs and heart act in accord, for the failure of either adequately to meet the demands of the moment may render nugatory the fullest effort on the

Digitized by Google

part of the other. For example, the breathing of an exhausted athlete, though it may be 15 or 18-fold that of his resting condition, does not of itself suffice to enable him to continue his exertion in face of inadequate circulation. Here the circulatory, and not merely the respiratory, system is at fault.

Instances of the opposite kind, namely, those in which distress is produced by the rate of oxygenation of the blood failing to keep pace with muscular demands though the circulation may be adequate, are of great practical interest. They include the case of the poison-gas patient (where the epithelial layer of the lungs is so thickened as to make oxygen-penetration difficult), the case of the high-flying airman (when the low barometric pressure and correspondingly low partial pressure of the atmospheric oxygen prevent proper oxygenation of the blood), and that of the so-called D.A.H. patient, where the extreme shallowness of breathing impairs the transfer of oxygen to the blood by insufficient exposure of epithelial area to the indrawn air. In the cases enumerated the inhalation of highly enriched air is immediately beneficial, and the means of administering it under a variety of conditions has been during the war, and still is, the subject of active study.

Fatigue.—The causes of the fatigue which results from heavy muscular exertion have not yet been fully analysed; but the experiments of Dr. Briggs, to be described presently, throw a very important new light upon them. During heavy muscular work the consumption of oxygen and production of CO_2 by the whole body are increased about ten times or even more. In the working muscles there must be a far greater proportional increase in consumption. The increase can only be obtained by an enormous increase in the circulation of blood through the muscles; and it is clear that, if an increased circulation cannot be brought about, the muscles themselves must fail from want of oxygen. Now it is known that when muscles are insufficiently supplied with oxygen they produce, and give off to the blood, lactic acid instead of CO_2. With a very excessive muscular exertion, such as running quickly upstairs, the circulation is completely inadequate to meet the oxygen-requirements of the over-taxed muscles; and it has been shown experimentally that the blood is at once flooded with lactic acid. This acid acts just like CO_2 on the respiratory centre, but, unlike CO_2, is not rapidly removed from the blood by the lungs. As a consequence, intolerable panting is produced, and the exertion is brought to a speedy end, partly by the ensuing distress, partly by failure of the muscles, and partly also by the general action of the abnormal blood in paralysing the central nervous system and thus causing stupefaction or even loss of consciousness.

With more moderate exertion the blood-supply to the muscles can be properly maintained, so that little or no lactic acid passes into the blood. Yet fatigue may develop rapidly, the most prominent symptom being distress as regards breathing It is on this form of fatigue that, as will be seen below, the new experiments throw a flood of clear light.

Nature of Physical Work.—Every-day experience assures one that a muscular task is easier when one is in good condition. It is equally certain that even a light task, involving external work, though easy to commence with, cannot be continued indefinitely without pause, and that the heavier the labour the shorter the time it can be sustained. Nevertheless, there are certain lesser degrees of exertion (for instance, cycling or walking at a moderate pace on a flat road) which, by the ease with which they can be kept up for hours on end, may be referred to, in electrical engineers' phraseology, as " normal loads "; while other and heavier tasks (for example, hard bayonet exercise or running quickly upstairs) are bearable for a limited period only, so that " overload " may permissibly be applied to them.

What may be an overload to one person is a normal load to another who is stronger or in better training or more habituated to the particular kind of labour. Again, a normal load when a person is fit may prove to be an overload when he is unfit; and, as has been remarked, even an easy, normal load, if long supported without rest, will eventually become an overload, and then the exertion has to be interrupted. It is evident, then, that the whereabouts of the dividing line between

a normal and overload for any individual depends on his condition at the time; if he is getting tired, it is moving down the scale of exertion; if resting, it is moving up.

Effects of Breathing Enriched Air.—It is well known that when air enriched with pure oxygen is breathed by a normal individual during rest there is no noticeable effect. When, however, a rescue apparatus is being used, the wearer is often doing pretty hard physical work. The effects of the extra oxygen during exertion have been carefully observed by Dr. Briggs in the course of the investigation, and the results throw a quite new light on fatigue.

It had often been observed before that some persons using a rescue apparatus derive great benefit during exertion from the enriched air. For instance, they can walk faster and more comfortably, in spite of the weight of the apparatus. This advantage is very marked in the case of two of us who have frequently experimented with rescue apparatus of every type. When, however, the enriched air was tested on practical miners, it was found that they seemed to derive little or no benefit from it. Their breathing was then investigated more closely, the expired air being collected in bags, measured and analysed. The very striking fact then appeared that, when ordinary air is breathed, the expired air of miners or other men in equally good physical training contains, during exertion, a much higher percentage of CO_2 and lower percentage of oxygen than that of men who are not in good training. In other words, less air is breathed by men in good training for a given consumption of oxygen or amount of work. There is, however, little or no difference in this respect when enriched air is breathed, unless the work is pushed to an extreme point. On the other hand, with men not in good training the percentage of CO_2 in the expired air becomes as high during exertion as in the men in training, so that the amount of air breathed for a given rate of work is considerably less with enriched air than with ordinary air.* The following Table, showing the results for two typical individuals, illustrates these points:—

TABLE 1.†

Work in ft. lbs. per min.	Per cent. CO_2 in expired gas				Litres gas expired per minute			
	Subject A		Subject B		Subject A		Subject B	
	Breathing air	Breathing oxygen	Breathing air	Breathing oxygen	Breathing air	Breathing oxygen	Breathing air	Breathing oxygen
Pedalling with brake off	3·9	4·1	4·4	4·5	12	13	14	11
3,000	4·65	5·25	5·3	5·45	25	22·5	20	18
6,000	4·7	5·8	6·2	6·2	40	33	27	27
9,000	4·3	5·8	6·1	6·3	54	43	37	37
10,000	4·1	5·7	6·0	6·2	57	46	40·5	40 5
12,000	—	—	5·6	6·0	-	—	50	48

How is the effect of enriched air on persons not in good training brought about, and why do those in good training respond so little to the enriched air? The answer to this question appears to be a very definite one. Recent investigations have shown that, during rest under normal conditions, the haemoglobin of the blood passing through the lungs has time to take up by the mere physical process of diffusion all the oxygen it is capable of taking up. When, however, during muscular

* It was found by experiment that, even with the least fit person, no advantage was to be secured by increasing the percentage of oxygen above 60. At the Physical Test Station, a regular oxygen proportion of two-thirds was obtained by causing the oxygen, after passing from the cylinder through a reducing valve, to issue from an injector nozzle. The injector drew in outside air through a small pipe controlled by a tap, and the tap was set by trial (and then soldered in position) so that the mixture passing forward to the receiving bag (from which the subject drew his supply) was 40 per cent. air. Allowing for impurity in the cylinder oxygen, such a mixture holds about 67 per cent. oxygen. This arrangement saved a good deal, oxygen being the main item of expense of the Station

† *Fitness and Breathing during Exertion*, by Henry Briggs. Journ. Physiol., LIII, 1919.

exertion, a far larger amount of oxygen has to be taken, there is not time for the haemoglobin to become fully saturated by diffusion alone if ordinary air is breathed, and, unless the epithelium lining the alveoli actively passes oxygen inwards, the arterial blood is imperfectly saturated with oxygen, and this makes the breathing faster and tends, as already mentioned, to exhaust the breathing powers. But the activity of the epithelium can be increased by practice. Hence, in men who are accustomed to muscular exertion, there is no deficiency of oxygen in the arterial blood when ordinary air is breathed until exertion is pushed to the utmost. For this reason they also receive no benefit from breathing air enriched with oxygen. On the other hand, in men who are not accustomed to muscular exertion, the epithelium fails to pass in the proper supply of oxygen unless the diffusion pressure of oxygen is raised in the alveolar air by the enriched inspired air. Hence these persons benefit by enrichment of the air with oxygen.

It would be out of place to attempt to discuss here all the evidence which supports this interpretation of the new facts described above; but in the present state of knowledge, no other interpretation seems at all probable. To produce the beneficial effects of the enriched air, it is not at all necessary that pure oxygen should be breathed. All that appears to be needed is air containing a considerably higher percentage of oxygen than ordinary air. It has often been observed by engineers that men work in compressed air (in caissons and in tunnels under water during construction) more easily than in ordinary air. In this case also the diffusion pressure of oxygen in the lung alveoli is increased by the compression. An investigation of their breathing would reveal the same phenomena as in the case of men using mine-rescue apparatus.

It is evident that the physiological response of a man to oxygen during muscular exertion furnishes an interesting test of whether or not he is in good training as regards his lungs. Physiological fitness depends not only on the lungs, but also on ready adaptation of the circulation, muscles, nervous system, &c., to whatever exertions are required. It is possible, therefore, that a man might be in a "fit" state as regards his lungs, but not fit otherwise. A stay at a high altitude, where the reserve power of the lungs is called upon even during rest, might, for instance, produce this condition. In ordinary cases, however, lung fitness is an accompaniment of general physical fitness, and may therefore be taken as a measure of it. Dr. Briggs has applied the new facts as the basis of a method of testing physical fitness; and this method was used during some months for Army purposes, as already mentioned. The same method is, of course, also applicable for the testing of members of a rescue brigade. A description of how this method can be carried out is therefore given in Appendix II.

Climbing, Walking and Running Tests.—(1) *Climbing Tests at Newbattle and Lingerwood.*—The first climbing experiments of this kind were made by Drs. Haldane and Briggs in November, 1917, in the Newbattle and Lingerwood pits of the Lothian Coal Co., Ltd., and their purpose was solely to determine the oxygen consumption while climbing mine inclines of different gradients, and while breathing ordinary air. To make the results more useful for rescue apparatus purposes, the subjects of the tests carried rescue apparatus in addition to the Douglas outfit (*see* Appendix II). The air of the roadway was in each case inhaled, the exhaled products being discharged over a timed period into the Douglas bag, which was carried on the chest. The volume of the bag was metered on the spot and samples of the air taken. Some of the samples were analysed by means of a Haldane apparatus fitted up in a pump-room underground, while others were dealt with in Dr. Briggs' laboratory. The experiments should be regarded as preliminary to the Burdiehouse tests described below. The table on p. 20, First Report, gave a summary of these results.

(2) *Climbing Tests at Burdiehouse.*—During the early part of 1918, a number of experiments were made on men climbing the main incline of the Burdiehouse limestone mine, both while breathing air and while breathing oxygen. The earlier tests, alluded to above, had shown the desirability of limiting the variables. This could be done either by taking one subject on a number of gradients, or by taking

a number of subjects on one incline, and the latter alternative was chosen as being likely to give more information. The Burdiehouse incline lies at the uniform slope of 21°. The roof is high, so that there was no occasion to stoop, and the floor, while dry for the most part, was, at the time of the tests, wet and slippery in places. On the whole, the "going" may be taken as a fair average of that in a mine roadway of heavy gradient.

Including, as it did, oxygen cylinders, meters, bellows, rescue apparatus, Douglas outfit, gas analysis apparatus, sample bottles, mercury, &c., a considerable equipment had to be carried by motor-car to the mine and then into the road. The physical difficulties involved made rapid work impossible, and we had to be satisfied with a comparatively few determinations for each subject. Usually values were obtained at five rates of speed, both when breathing air and when breathing oxygen.

During the Burdiehouse climbing tests the manner of use of the Douglas bag differed from the usual in that the bag was made the reservoir out of which the man drew air or oxygen during the timed period, instead of being the receptacle for expired air. At the commencement of a test this bag was inflated with a measured volume of air or oxygen. In the case of air a large double-acting smoke-helmet bellows was used to supply the air, while in that of oxygen the gas was admitted, through a dry meter, from a small cylinder. The expired air or oxygen was made to pass into a Proto bag hung in front, over the rescue apparatus bag, and fitted with an automatic relief valve.

When breathing air, the subject walked at the desired rate up the incline (which was marked-off in chains and poles) until it was judged that his respiration had adjusted itself to the degree of exertion; the 3-way tap was then turned and air drawn from the Douglas bag until that bag was almost flat, when the tap was turned off and the mouthpiece at once removed so as to conserve the expired products collected in the Proto bag. Samples were then drawn from the latter, and the volume of air remaining in the Douglas bag was measured.

Before any values were obtained on oxygen, the subject was required to use the rescue apparatus for some time in order to wash out the bulk of the free nitrogen dissolved in the blood and tissues. During this period the nitrogen was expelled from the rescue apparatus by using the by-pass from time to time. He was then not permitted to breathe air again until the whole of the oxygen series was completed; during spells of rest, and during the first part of a climb while the respiration was accelerative, he used the rescue apparatus. On switching on to the Douglas bag he rapidly changed mouthpieces, an operation which was repeated the moment the exertion was stopped.

All distances are recorded on the incline and not on the flat. The external work performed per minute was evaluated in ft. lbs. by multiplying the gross weight in lbs. (man *plus* apparatus carried) by the rise in feet per minute.

The weight carried was the same, within a pound or two, for every subject, and averaged 43 lbs.

(3) *Walking and Running Tests.*—These were conducted in the observation court (level cement floor) of the Edinburgh Rescue Station, the appliances and routine being the same as those of the Burdiehouse tests.

Oxygen Consumption during Exertion.—A full account of the experiments with the ergometer and on men climbing, walking and running will be given in a separate paper now being prepared for the Royal Society of Edinburgh. It is, however, advisable here to set forth in tabular form the oxygen consumptions determined in these experiments, since the question of oxygen supply during physical exertion is of the first importance to the designer or user of mine rescue apparatus. Attention is directed to the variations in oxygen consumption between one man and another, and to the high figures sometimes reached.

A description of Subjects I, II, V, VII, and VIII is given in Appendix II; the following facts relate to the others included in the tables:—

Subject III.—Rescue station instructor: weight, 165 lbs.; fitness (from ergometer test), 80 per cent.

Digitized by Google

Subject IV.—Mine under-manager: weight, 168 lbs.; trained rescue man; engaged in a pit working flat seams; fitness 64 per cent.

Subject VI.—Army recruit, previously bank clerk: weight, 142 lbs.; fitness, 42 per cent.

Subject IX.—Mine fireman in a pit working flat seams: weight, 168 lbs.; trained rescue man; fitness 69 per cent.

Subject X.—Featherweight boxing champion of Great Britain, working as a rivetter at time of test; not in fighting training; weight 133 lbs.; fitness 77 per cent.

Subject XII.—Army officer: fitness, 93 per cent.

Subject XIII.—First-class footballer, runner, jumper and all-round athlete, Army instructor in physical drill; weight 158 lbs. Records were obtained on this subject in three conditions—(1) in good health; fitness 70 per cent. (the ergometer results labelled (*a*) were obtained on this occasion); (2) in good health and after intensive physical training at Aldershot; fitness 100 per cent.; and (3) in poor health; fitness 55 per cent. The climbing and walking tests and also the ergometer tests marked (*b*) were carried out with the subject in the last condition.

Subject XIV.—Army officer doing sedentary duty; had been wounded through the groin; weight, 161 lbs.; fitness, 62 per cent. Formerly a long distance runner.

Subject XV.—Rescue station assistant instructor: weight, 147 lbs.; fitness, 63 per cent.

Subject XVI.—Research assistant: sedentary habits; weight, 154 lbs.

Subject XVIII.—Instructor in physical drill at an officers' hospital: weight, 166 lbs. Fitness deteriorating: 56 per cent.

Subject "C.G.D."—The information relating to this subject (*a*) when walking at different rates on a laboratory floor, and (*b*) when walking in a grass field, have been extracted from Haldane and Douglas' paper entitled "The Capacity of the Air Passages under varying Physiological Conditions" (*Journ. Physiol.* 45, 1912, p. 235) and are given here for the sake of comparison. To make the oxygen consumptions more strictly comparable with our determinations, it has been necessary to add 25 per cent. to the published figures to allow roughly for the fact that the subject did not carry a weight of 43 lbs. in addition to the Douglas outfit.

The oxygen consumed is, in all cases, expressed in litres per minute, the gas being dry and at 32° F. (0° C.) and 30 ins. barometer.

TABLE 2.

Oxygen Consumption.

Walking and Running on the Flat, carrying weight of 43 lbs.

Subject.	Miles per Hour.											
	Standing.		1.		2.		3.		4.		5.	
	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.
I.	·71*	·68*	·77	·91	·85	1·14	·95	1·40	2·12	2·22	3·0	2·8
II.	·47	·53	·59	·59	·80	·74	1·15	1·06	1·68	1·59	2·2	2·1
III.	·25	·41	·64	·47	·90	·70	1·17	·96	1·62	1·78	2·3	2·8
XIII.	·31	·28	·60	·63	·88	1·00	1·20	1·38	1·60	1·75	2·9	2·4
XVI.	·55	·57	·70	·84	·92	1·22	1·31	1·65	2·09	2·11	3·4	2·7
Average	·40	·45	·65	·69	·87	·96	1·16	1·29	1·82	1·89	2·8	2·6
C.G.D. (*a*)	·40	—	·60†	—	·84	—	1·14	—	1·47	—	2·65	—
C.G.D. (*b*)	·40	—	·67†	—	·98	—	1·33	—	1·99	—	3·17	—

* Unusually high; omitted in averaging.
† Interpolated from the graph.

Digitized by Google

TABLE 3.

Oxygen Consumption.

Climbing Mine Incline of 21°, carrying 43 lbs.

Subject.	Work done in Foot pounds per Minute.							
	Standing.		3,000.		6,000.		9,000.	
	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.
I.	·62	·57	1·08	1·37	2·02	2·17	3·1	3·0
II.	·42	·40	1·14	1·19	2·20	2·55	—	3·4
III.	·35	·41	1·14	1·09	2·19	2·05	—	—
XIII.	·47	·45	1·40	1·24	2·56	2·37	3·1	2·6
XVI.	·45	·47	1·24	1·24	2·02	2·02	2·8	2·85
Average ...	·46	·46	1·20	1·23	2·20	2·21	3·0	3·0

TABLE 4.

Oxygen Consumption.

Climbing Mine Incline of 21°, carrying 43 lbs.

Subject.	Speed in Miles per Hour; Slope Measurement.							
	Standing.		0·5.		1·0.		1·5.	
	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.	Breathing Air.	Breathing Oxygen.
I.	·62	·57	1·10	1·40	2·18	2·25	3·2	3·1
II.	·42	·40	1·10	1·14	2·15	2·50	—	3·4
III.	·35	·41	1·25	1·19	2·45	2·30	—	—
XIII.	·47	·45	1·20	1·31	2·70	2·46	3·2	2·7
XVI.	·45	·47	1·26	1·26	2·04	2·04	2·8	2·9
Average ...	·46	·46	1·24	1·26	2·30	2·31	3·1	3·0

TABLE 5.

Oxygen Consumption.

Ergometer Results.

Subject.	Work done in Foot-pounds per Minute.							
	Resting.		3,000.		6,000.		9,000.	
	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.	Breathing Air.	Breathing O_2.
I.	0·28	0·31	1·23	1·05	1·77	1·55	2·42	2·15
II.	0·23	0·31	1·23	1·20	2·08	1·82	2·42	2·30
III.	0·37	0·22	1·03	0·81	2·62	1·30	2·20	2·10
IV.	0·33	0·28	1·12	0·95	1·68	1·61	2·04	2·30
V.	0·28	0·37	1·17	0·81	1·80	1·44	—	—
VI.	0·47	0·40	1·17	1·02	—	—	—	—
VII.	0·45	0·40	1·13	1·05	1·70	1·49	2·37	1·90
VIII.	0·42	0·32	1·05	0·97	1·58	1·50	2·27	2·00
IX.	0·40	0·30	1·00	1·05	1·68	1·62	2·30	2·30
X.	0·37	0·28	1·12	0·81	1·83	1·28	2·52	1·70
XII.	0·40	0·41	1·07	0·92	1·58	1·54	2·09	2·02
XIII(*a*)	0·33	0·45	0·70	1·05	1·17	1·54	1·75	2·20
(*b*)	0·37		1·30		2·00		2·65	
XIV.	0·38	0·25	1·17	0·92	2·09	1·65	2·62	2·52
XV.	0·25	0·35	1·07	0·98	1·63	1·50	2·30	2·30
XVIII.	0·42	0·24	1·30	1·00	2·00	1·67	2·71	2·31
Average	0·36	0·32	1·12	0·97	1·74	1·54	2·33	2·16

Digitized by Google

Most Economical Rate of Walking.—If a rescue man's purifier or oxygen begin to fail while he is still a good way from fresh air, he is faced with the question: What is the best speed at which to proceed? He may forfeit his life to an incorrect answer. Unless thoroughly instructed, he will be tempted to make a rush for the base, to get the journey done in the shortest time; he would be risking a great deal by giving way to that temptation. In the case of an apparatus fed with a uniform two litres of oxygen per minute, and where the oxygen is running dangerously low while the purifier is still serviceable, the best speed of retreat is evidently that at which two litres per minute are consumed by the wearer. But in the case of the purifier failing in any class of apparatus while the oxygen reserve is still adequate, or in the instance of a Weg or a Gibbs apparatus (where the oxygen delivery is automatically regulated to the demand), in which the cylinder is nearly run down, the problem takes on a new complexion. The best speed of retreat would then be that at which the required distance may be traversed with the minimum output of CO_2 and the minimum consumption of oxygen. Like a steamer or an airship, a man has a most economical speed at which he goes furthest per litre of oxygen or per pound of food. To ascertain that speed is thus of practical value to those using rescue apparatus, and also (it may be added) to those concerned with the economical movement of infantry.

The data of Table 2 (oxygen consumption during walking) yield the following information on the matter:—

"C. G. D.'s" most economical rate, breathing air and walking without burden on a laboratory floor, was four miles per hour, at which speed he moved 99 yards on a litre of oxygen. Walking without burden in grass, the same subject's most economical rate was three miles per hour, when a litre carried him 82 yards. With all the remaining subjects of Table 2—loaded, as each of them was, with a weight of about 43 lbs.—the most economical speed proved to be three miles per hour when breathing air, while, when breathing oxygen and similarly loaded, that rate was three miles per hour for Subjects I, II and III and four miles per hour for Nos. XIII and XVI. It is apparent that increased difficulty of walking, whether due to the man carrying a load or to lack of smoothness of the path, reduces the most economical speed. Under the conditions obtaining in the mine we judge that rate to be about 2½ miles per hour when travelling a flat road and carrying a rescue apparatus.

PART II.

DEATHS DUE TO RESCUE APPARATUS.

In the following list we give particulars of the 14 deaths that have occurred in British mines through the use of rescue apparatus:—

TABLE 6.

Date.	Colliery.	Probable Cause of Death.	Number of Deaths.	Apparatus.
March, 1908 ...	Hamstead	Heat stroke	1	Weg.
November, 1911	Felling	Defective apparatus	2	Draeger.
August, 1912 ...	Cadeby	Removed mouthpiece in poisonous air.	1	Draeger.
November, 1912	Cae Duke	Leaky apparatus	1	Draeger.
June, 1913 ...	Elswick (disused adit)	Oxygen turned off	1	Proto.
November, 1916	Newdigate	Apparatus improperly adjusted ...	2	Proto.
March, 1917 ...	Duchy	Defective apparatus	2	Draeger.
January, 1918...	Podmore Hall (Minnie Pit).	Apparatus improperly adjusted ...	1	Proto.
April, 1919 ...	Newliston (Shale Mine).	Leaky apparatus	3	Proto.

We view with apprehension the large proportion of casualties attributed to improperly adjusted and leaky apparatus. The statistics of deaths force upon us the conclusion that insufficient attention has been paid at some centres to the methods of testing and adjustment. Obviously it is not enough for an apparatus

to be constructed on correct lines; it must be proved serviceable by test before being used. We agree with Lt.-Col. Logan's maxim that every rescue apparatus should be regarded as unsafe until it has been proved otherwise.

The Newliston Mine Accident.—Three men wearing Proto apparatus lost their lives while combating an underground fire in the Newliston Oil-shale Mine on April 18, 1919. Dr. Briggs examined the apparatus used by two of these men, and made a report thereon to the Chief Inspector of Mines, of which the following is a digest. The third body and apparatus have not as yet been recovered. Medical evidence was to the effect that the deaths were due to carbon monoxide poisoning.

While at the mine, it was seen that the unions attaching the flexible inhalation tubes to the bags were slack in both apparatus. In one case the union had been put on "across the thread," and was only caught by two or three threads. On being subsequently tested under water, dangerous leaks were revealed in both apparatus in addition to those at the loose unions. In both cases there was leakage of high-pressure oxygen, which in one instance amounted to 2 litres per minute at a cylinder pressure of 25 atmos. Still more serious were the leakages on the breathing circuits. The bag of one apparatus leaked badly at one end of the large rubber-to-rubber joint, owing to the opening being larger than the clamp intended to close it. It was found impossible to make a secure joint at this place. There was a small leak at the inspiratory valve screw of the same apparatus and a large leak between the rubber and metal portions of the mouthpiece, due to the binding being insufficiently tight. Leakage at the latter place is especially dangerous (*see* First Report, p. 16), as it is at the mouthpiece that the extreme alternation of pressure occurs. With both apparatus the leaks were such that positive internal pressure could only be obtained by aid of the by-pass, and even then it was quite transitory. A number of other tests were applied, but as they gave negative results they may be disregarded here. The following conclusions were given in the report:—

"If the apparatus were used in air fouled by whitedamp and were worn in the state in which they were found by the writer, Brodie's and Laird's deaths were due to poisoning by carbon monoxide drawn in through the leaks in the breathing circuit of the apparatus.

"The leakage of oxygen at the high-pressure taps and joints was not a contributory cause of death; its occurrence in these apparatus, however, suggests one possible reason for the unduly rapid fall in the oxygen pressure which appears to have been a feature with several of the apparatus used by members of the exploring brigade.

"In the First Report of the Mine Rescue Apparatus Research Committee, 1918, (p. 31), it is recommended that no rescue apparatus should ever be used in poisonous air until it has been tested by immersing it in water with the oxygen turned on and the mouthpiece closed. Had this method been applied in the cases in question it is probable that the fatalities would not have occurred."

Certain of the views elicited under cross-examination at the Fatal Accident Inquiry following upon the Newliston accident call for comment:—

(1) **The Nose-clip Danger.**—In the opinion of the instructor and other members of the brigade, the fatalities resulted from the nose-clips being displaced. These were of the "ratchet" pattern—a variety which is particularly liable to be knocked off, and which on that account should be abandoned. While not wishing to minimise the danger attendant on a defective clip, we think that unless the wearer is already suffering from the effects of CO, CO_2, or want of oxygen, the dropping of a clip, even if a breath or two of foul air is inhaled before it is replaced, will not cause risk of his falling immediately unconscious. Indeed, had the blood on this occasion been free from CO, the effect of a few breaths of the foul air would have been imperceptible. The probability is that, in each of the cases in point, the blood was highly saturated with carbon monoxide drawn in through the holes in the breathing circuit before the man stumbled and knocked off his clip. With the frequent use of the by-pass the inhaled air would contain a

Digitized by Google

large percentage of oxygen, and the wearer of the apparatus would thus be able to support a higher concentration of CO in the blood than if he had been respiring normal air contaminated by that gas (*see* p. 16, *First Report*); but when the limit of endurance was reached and he was staggering, the displacement of the nose-clip and inhalation of air through the nose would result in almost immediate unconsciousness because of the indrawing of air low in oxygen.

(2) **Positive Pressure.**—The rescue station superintendent held the opinion that, even if there were leaks in the circuit, the flow would be outward and not inward, because of the Proto being a " positive pressure " apparatus. A small puncture in, say, the Proto bag is much less dangerous than the same-sized puncture in the purifier of the Meco apparatus, because the resulting leakage in the first instance will usually be outwards and in the second instance usually inwards; but when the holes are large or numerous, there is no way of maintaining a continuous positive pressure in any breathing apparatus; instead of that, the pressure in the circuit constantly tends to equalise itself with that of the surrounding atmosphere; in other words, there is outward flow through the leaks on expiration and inward flow during inspiration, no matter of what type the apparatus may be.

As demonstrating this effect, one of the Newliston apparatus, with the union on the inspiratory tube set as nearly as possible as it was when the apparatus was received by Dr. Briggs, was fitted with a special appliance to measure the volume drawn in through the leak while not interfering with any outward discharge. The wearer was set to do work on the ergometer at a rate which was known from experiments to be approximately equivalent to that of climbing a mine incline of 1 in 6 at a speed of $1\frac{3}{4}$ or 2 miles per hour. The inflow from the outer air averaged 0·8 litres per minute, and heavier exertion would have led to a greater inflow. There was, on inspiration, a negative pressure of half an inch of water at the point.

(3) **The Water Test.**—Though admitting the good qualities of this test for leakage, the superintendent took exception to it on the grounds that it wetted the apparatus and made it uncomfortable to wear, and that the outer cover of the Proto bag got full of water during the test. As was pointed out by Mr. H. Walker during the Inquiry, the last drawback is remedied by providing one or two small holes at the bottom of the cover through which water may drain away. A rather more cogent reason against the test as described in the *First Report*, p. 31—where it was suggested that, before immersion, the slings and bag-cover of the Proto should be removed—was that if this test were carried out, the bag joint would have to be broken and remade in replacing the cover, and that there was, therefore, no guarantee that the joint was secure when the apparatus was ready for use. The testing of rescue apparatus for leakage is manifestly of such importance as to make it advisable to discuss it separately below.

(4) It was argued that the unions may have been loosened by rough usage of the apparatus between the time of the accident and the examination, or that, subsequently to the accident, the tubes may have been disconnected and imperfectly reconnected by some person unknown. This is possible; but the leak at the mouthpiece and that at one end of the bag-joint cannot be so explained away, and they were sufficient in themselves to account for the death of one of the men.

Testing Rescue Apparatus for Leakage.—Leaks, even at the high pressure joints, do not always make a noise; to depend entirely on hearing a leak is not, therefore, to be recommended. The method of using a glowing cigarette or match-end is generally more successful in detecting leakage of oxygen from the supply parts of the apparatus than in spotting leaks on the breathing circuit. It cannot be too often emphasised that, even with the so-called " positive pressure " apparatus, a serious leak on the breathing circuit, especially at a place near the mouth, leads to inflow as well as to outflow of air, and during inflow the hole may escape detection by the cigarette test. That test also has obvious limitations underground. To test an apparatus at the pit head by wearing it in a closed room full of sulphur fumes cannot be recommended for four reasons: (1) The test is slow and troublesome; (2) it does not reveal leakage from the oxygen supply; (3) an entry of the fumes into the breathing circuit at a point from which the

air has to flow through the purifier before reaching the mouth may pass undetected, since caustic soda absorbs SO_2; and (4) if a leak is discerned, there is no precise indication of its position.

It has been proposed to use a watergauge attached to the breathing circuit as a leakage indicator, the apparatus being inflated and the rate of fall of the gauge observed. The method, however, suffers from the demerits (2) and (4) above, as well as from the objection that a joint has to be remade when the gauge is removed, unless the gauge is applied at the orifice of the rubber mouthpiece.

We know of no test of leakage to equal that in which the apparatus, tightly distended and with the oxygen on, is plunged under water. The water test scrutinises both the breathing circuit and the high-pressure joints; it not only detects leakage, but also shows at once where it occurs. As was illustrated on the occasion of the Wallyford fire (January, 1919), where every apparatus was subjected to it before being taken underground, the water test is readily applied at the pit-head, a collapsible bath being taken out from the rescue station with the rescue apparatus. The fact that every man witnessed the testing of his apparatus on that occasion was responsible, according to the Instructor (Mr. J Cooper), for increased confidence.

The fact that the test wets the apparatus has been advanced as a serious disadvantage. A slight and transitory discomfort is barely worth mentioning when pitted against the safety of the wearer.

As has been recently observed,* it is advisable to shake the connections when under water, as a slack joint may be passably gas-tight in one position and leak badly in another. A suitable way of testing the Proto is, first, to put it under water in an inflated condition, with the belt and bag cover removed—when the connections and tubes can be scrutinised and the rubber bag can be examined for punctures—and, second, to replace the belt and bag cover, and then, with the bag upside down, to immerse the bag-joint to make sure that it is tight. In this way most of the cover is kept dry. As has been pointed out, it is not sufficient that the test be applied with the cover off, for, in replacing the latter, the bag joint has to be remade after testing.

The water test is essentially a pit-head test; it will be only rarely that it can conveniently be employed at an underground base. If a secure method is used of connecting a water gauge to the rubber mouthpiece orifice and also of applying suction, it would form a serviceable alternative to the water test for testing the breathing circuit, though not the high pressure parts.

We repeat, that no rescue apparatus should be used in a poisonous atmosphere unless it has passed a satisfactory leakage test.

PART III.

APPROVAL OF MINE RESCUE APPARATUS.

If the Home Office agrees to institute a system of testing rescue apparatus in order that those satisfying the tests may be regarded as "approved apparatus"—and that formed one of the most important recommendations of our First Report—it will be necessary to adopt a definite routine for the examination, so that makers will be aware of the standards of performance that have to be reached. Several of the requirements of apparatus were defined in the First Report, and these will be found to have been incorporated in the following suggested conditions of test:—

Suggested Conditions and Character of Official Test of Two-hour Rescue Apparatus.

1. The maker of the apparatus, or his agent, shall send to the testing officer two identical models of the apparatus to be tested, along with such cartridges or chemicals (excepting oxygen or liquid air) as will enable the following tests to be carried out. The maker shall also send such additional parts and additional cartridges or chemicals as the officer may request. Should an apparatus fail to comply with the requirements, the two said models will be returned to the maker:

* G. L. Brown, *Trans. Inst. Min. Engs.* LVII, p. 154.

Digitized by Google

in the event of an apparatus receiving approval, one model will be retained by the officer on behalf of the Home Office. Along with the apparatus the maker shall also forward to the officer a clear drawing of the apparatus to indicate its manner of working, and a complete schedule of parts of the apparatus stating the material of which each is made, and the name by which it is proposed that the apparatus shall be known.

2. A rescue apparatus shall only be allowed to be used in mines—If (*a*) it has satisfactorily passed the tests outlined below, and has received the official certificate of approval; (*b*) it is made in the manner and of the materials specified in the description which is attached to the official certificate of approval; and (*c*) it be provided prior to use with the kind and amount of consumable charge stipulated in the said description: or if (*d*) it has been approved for experimental purposes by an inspector designated by the Home Office.

3. In the event of the manufacturer desiring to make an alteration in an apparatus already approved, application shall be made to the Under Secretary of State, Home Office, Whitehall, defining the exact nature of the proposed alteration. The Secretary of State will then decide whether the proposed change is of so fundamental a character as to necessitate complete re-testing in the manner herein prescribed; whether it necessitates re-testing in part only or to a modified extent, or whether the alteration may be permitted without further testing.

4. If more than one manufacturer desire to make a particular apparatus, each manufacturer shall comply with the conditions here set forth, irrespective of any approval previously granted on that apparatus to any other maker.

5. Approval may be cancelled in respect of an apparatus which is found, subsequent to approval, to be made by a manufacturer of inferior materials or involving inferior workmanship.

6. The maker shall be allowed to be represented at the tests of an apparatus or part thereof.

7. In the event of an apparatus, or part thereof, failing to comply with the requirements, a report will, if desired, be furnished to the manufacturer setting forth the cause or causes of failure.

The report on an apparatus which has failed to comply will not be made public by the Home Office.

8. A rescue apparatus shall undergo the following examination and tests:—

(*a*) **General Construction and Serviceableness.**—The apparatus shall be constructed of the best available materials and be of mechanical strength sufficient to withstand the usage it is likely to receive in actual service. The parts shall be arranged with due regard to the comfort of the wearer and shall have been designed on correct mechanical principles. The apparatus shall not unduly impede the wearer when he is walking in a crouching position or when he is crawling. The arrangement shall be such that the parts can easily be tested, inspected and repaired.

In the case of compressed oxygen apparatus, a gauge shall be provided to enable the reserve of oxygen to be read at any time. The gauge shall be within view of the wearer, and, if it is connected to the cylinder by a flexible tube, there shall be a cock or other efficient means of shutting off the gauge and flexible tube from the cylinder. Such apparatus shall have one cylinder only, and the cylinder valve shall be either so constructed that it cannot accidentally be closed, or provided with a suitable locking device serving that purpose. There shall be a by-pass to permit of a free flow of oxygen from the cylinder to the breathing circuit of the apparatus independent of the reducing valve. There shall be a relief valve (preferably operating automatically) on the breathing circuit, and if it be automatic in action, the construction of the apparatus shall be such as will prevent the bag being accidentally squeezed flat.

Unless an apparatus complies with these general requirements, it shall be rejected without further examination.

(*b*) **Purifier Test.**—If the material used for absorbing carbon dioxide is contained in a sealed canister or cartridge, the latter shall be so constructed that the absorbent cannot be so disturbed by shaking as to impede the flow of air through it, or to create open passages or short-circuiting within the cartridge.

Digitized by Google

Unless the design of the cartridge is such as definitely to preclude any such movement of the absorbent, three sealed cartridges will be subjected to shaking or vibration for three minutes and then tested separately by either (1) passing through each of them, in an intermittent flow, air saturated at blood temperature and containing carbon dioxide of a volume and proportion to represent the expiration of an average man walking at 4 miles per hour for a period, in each case, of 2 hours, or (2) by attaching each cartridge to an approved rescue apparatus and subjecting it to the endurance test as set forth in (*d*) below. Measurements of resistance (by water-gauge) and samples of the air discharging from the cartridge will be taken at intervals. The purifiers will be regarded as having satisfied the test if the highest recorded resistance due to the purifier alone is under 2 ins. of water column, and if the highest CO_2 proportion in the air passing from the purifier is under 2 per cent.

This test will not be applied to a purifier forming part of a liquid air apparatus in which the supply of fresh air to the wearer is so copious that the greater part of the expired air discharges to waste without passing through the cartridge.

(*c*) **Tests of Expiration and Inspiration Valves.**—If the valves on the breathing circuit possess novelty of design or arrangement, tests will be made to ascertain their efficiency. A valve shall not be regarded as satisfactory if its slip in any position exceeds 20 per cent. when the volume being respired is 40 litres per minute.

(*d*) **Endurance Test.**—This test will be performed four times, namely, twice with each of the models submitted by the manufacturer, and the apparatus will be worn by different persons on each occasion. Persons accustomed to using rescue apparatus will be selected to wear the apparatus.

The person wearing the complete apparatus shall walk at a regular rate of 4 miles per hour on the level for a period of 2 hours, with rest intervals of not more than 5 minutes each at the expiration of 30, 60, 90 and 105 minutes, when samples of air and thermometer and other readings may be taken. Samples and readings shall also be taken at the end of the two-hour period.

In the case of an apparatus dependent on a uniform oxygen delivery, the rate of delivery will be set at 2 litres per minute before the commencement of the test, and the rate will again be measured at the end of the test. Before an apparatus is put on, it will be tested for leakage and any leak remedied. An examination for leakage will also be made after the two-hour period. Unless the apparatus derives its oxygen supply from the evaporation of liquid air, only oxygen of at least 98·5 per cent. purity will be used in this and the subsequent tests, and the cylinder will first be washed out with such oxygen before charging.

Samples of air from the inspiratory tube of the breathing circuit will be taken at intervals and analysed forthwith for carbon dioxide and oxygen. The temperature of the inspired air and the cylinder pressure will also be recorded at each interval.

An apparatus shall not be regarded as satisfactory unless (1) it proves itself, on each of the four endurance tests, to be able to meet the wearer's requirements for the full period of 2 hours; (2) the highest CO_2 percentage in the samples taken does not exceed 2 per cent.; (3) the highest temperature of the inspired air is not more than 20° C. (36° F.) in excess of the temperature of the atmosphere at the time the maximum reading was taken; and (4) the highest resistance of the apparatus as a whole (measured immediately at the end of the two-hour period) does not exceed 3 inches of water when the rate of flow is 85 litres per minute.

(*e*) **Training Gallery Test.**—This test will be undertaken in irrespirable air in a suitable gallery. Two men, each equipped with the apparatus, will work two hours in the gallery. The men will be required to undertake a definite programme involving varied exertion for two hours. The programme may include weight lifting, weight carrying, loading a mine tub, tramming, carrying a dummy figure on a stretcher, crawling through low narrow openings, and sawing and setting timber. The test is mainly to determine the degree of security and comfort attainable when wearing the apparatus and when performing some of the common tasks of mining, and the nature of the work will be in all cases arranged by the testing officer as may

be deemed by him most suitable to reveal the defects or limitations of the particular apparatus.

9. A nose-clip shall be so constructed, or so attached, as to afford reasonable security against accidental displacement through a chance blow, or through the wearer stumbling. It shall not tend to slip when the nose becomes moist with perspiration.

10. A face mask shall not be approved for use with mine rescue apparatus unless it passes all the tests imposed upon it by the testing officer.

11. Approved rescue apparatus, or parts thereof which have been separately approved (excepting nose clips), shall, before leaving the maker's works, be stamped or otherwise clearly marked with (1) the maker's name and serial number; (2) the inscription "Mine Rescue Apparatus: Approved for Use in Mines in the United Kingdom," and (3) the date of approval. It shall be illegal for a maker to stamp or mark apparatus in this manner unless he has, on his own behalf, obtained approval for the apparatus.

12. The approval of a mine rescue apparatus, or part thereof, has reference only to the question of its safety for use, and takes no cognisance of the legal right of a manufacturer to make the apparatus. The certificate of approval is not to be regarded as equivalent to a licence to manufacture the apparatus or part in question.

PART IV.

MISCELLANEOUS.

Qualifications of Rescue Station Instructor.—General Regulation 144 states: "Every Central Rescue Station shall be placed under the immediate control of a competent person conversant with the use of the appliances." Though the responsibility for operations with rescue apparatus, in common with all other operations at a mine, devolves upon the manager, the rescue station instructor must necessarily be consulted as to the feasibility of any proposed course of action with the apparatus, and as the specialist on such matters, his advice must often be sought and followed. We consider it advisable not only that he should be capable of giving a sound opinion, but also that his views (especially as to the safety or otherwise of rescue operations) should carry weight. To possess the character, knowledge and status desirable in the holder of a position of this responsibility predicates a standard a good deal beyond a bare acquaintanceship with the use of the appliances at the station, and, in future, before an instructor is appointed, we think that his qualifications in these respects should be carefully scrutinised.

Cooling the Inspired Air, Proto Apparatus.—All users of the Proto agree that the high temperature attained by the inspired air constitutes a most serious drawback, and, as was shown in the Doncaster Report, other forms of apparatus may develop the same defect when they are used in warm air. On occasion, the hot saturated air produces an insufferable burning of the mouth and throat. The most serviceable method of cooling which we have so far tried is a modification of that of the Doncaster experiments,* where a bag containing sodium sulphate (suggested for this purpose by Mr. T. F. Winmill) was placed between the wearer and the inspiratory compartment of the Proto bag. The success of the method was demonstrated at Doncaster, and it has been applied at other rescue stations and in France during the war, the salt being contained either in a third compartment next to the wearer, or in separate small bags lying on top of the caustic. The latter variant was tried at Crumlin in 1917 by Mr. A. T. Winborn and Mr. R. J. Currie,† who reported very favourably on it. In one instance, where two Proto men, one with cooling bags in his apparatus and the other without, were pitted against each other in a 2-hours programme of strenuous work, the latter had to stop in one hour owing to excessive heat. The temperature of his inspired air was then found to be 130° F. The first completed the 2-hours task, the temperature of the indrawn air being 87° F. at the end of the period. Other tests gave similar results.

---

* *Second Doncaster Report, p. 12.*
† Also see *Colliery Guardian, Vol. CXVIII, p. 238.*

Digitized by Google

Hydrated sodium sulphate (Glauber's salt) melts at 92° F., and in melting absorbs a large amount of heat; but extended observation has shown it to be not very suitable for the purpose in view. It has the peculiar property of depositing the anhydrous salt if it be heated above 92° F., as would of course occur if it continued in contact with the purifier after being completely liquefied; and the higher the temperature to which the fused salt is raised, the greater the proportion of anhydrous sulphate precipitated. Thus, a bag of Glauber's salt, raised first to a higher temperature than its melting point and then allowed to cool, is found to contain partly the salt in its original state, partly anhydrous sulphate and partly a saturated solution; and the last two are of limited use as heat absorbers. This action tends to be cumulative, as its impaired cooling power would probably result in the bag attaining a still higher temperature when it was next used, and a further decomposition of the hydrated sulphate would then occur. In place of sodium sulphate, Miss Gilchrist suggested hydrated calcium chloride ($CaCl_2 6H_2O$), which melts at 84° F., and which, as it returns to its original condition on cooling, can be used any number of times. Experiments have also been made on sodium chromate ($Na_2CrO_4 10H_2O$), which liquefies at 74° F.

Calcium chloride, though it has proved an excellent cooling medium, has the disadvantage that, in the event of its containing bag or tube being punctured, the resulting mixing of the chloride with the soda and sodium carbonate of the purifying charge leads to a considerable evolution of heat.

If the apparatus is to be worn in hot mines, failure may result from the rise of the wearer's body temperature, caused by the hot bag being insufficiently insulated from the body, rather than from the temperature of the inhaled air. In such circumstances the 3-compartment bag, with the cooling agent in the sealed compartment nearest to the body, affords a most effectual safeguard, though the benefit is obtained at the cost of a bag which protrudes awkwardly.

On the other hand, if the problem is to improve the capacity of the Proto apparatus for hard work in places where the temperature of the atmosphere is not unduly high, attention has then principally to be directed to cooling the purified air, and the ideal situation for the cooling agent is in contact with the regenerated air but not in contact with the caustic soda. If the cooling agent in this instance be placed, for example, in a few small bags resting on the soda, its usefulness is diminished by it absorbing heat from the caustic rather than from the air leaving the caustic. Moreover, the small bags are apt to work down into the soda, where the salt soon melts; and, if of rubber, they run the risk of being punctured when the charge is kneaded or shaken up.

We have tried using a calcium chloride cooler attached to the top of the bag and placed outside it, but all such arrangements are clumsy and unsatisfactory. The best method of applying the cooling salt which we know at present, is to place it in sealed, round-ended tubes of thin metal, each being about 6 ins. long and 1¼ ins. in diameter.* These are dropped into a special small compartment (*A*, Fig. 1),

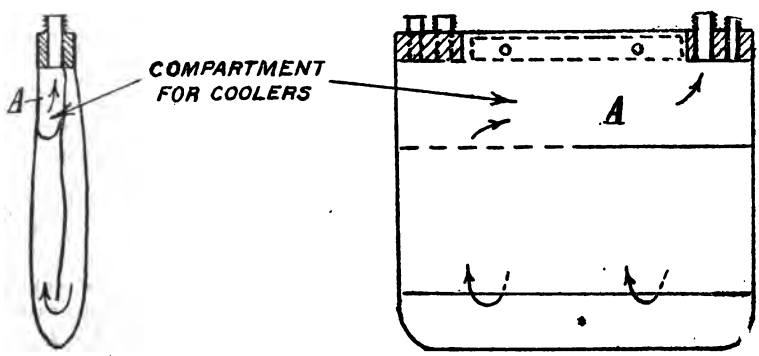


FIG. 1.—Proto bag with Cooling Compartment.

* Such a tube holds about half a pound of hydrated calcium chloride. For experimental purposes we have used lengths of the inner tube of a bicycle tyre, but the metal tube is preferable as it reduces the chance of puncture to negligible proportions.

Digitized by Google

through which the regenerated air has to flow on its way to the inspiratory tube of the apparatus. So placed, the risk of puncture is small, and the cooler is kept off the caustic. Any desired number of the tubes can be inserted. Usually, four are found sufficient.

Oxygen Purity.—On the whole, the oxygen supplied to rescue-stations appears to be much freer from impurity than it was in 1917. Almost invariably at the present time, that obtained at the Edinburgh, Porth, and Doncaster stations contains less than 2 per cent., and generally less than 1·5 per cent., of nitrogen. The position is not so favourable at Newcastle, where the oxygen received often has over 1·5 per cent. impurity, while in September, 1919, the nitrogen-content reached the dangerous level of 8 per cent.

All the more progressive rescue stations have installed analysis apparatus or have arranged for the analyses being carried out by an independent chemist. Oxygen purity is a matter demanding constant watchfulness, and it is evidently impossible to depend on a works' guarantee.

Prevention of Rusting of Oxygen Cylinders.—The formation of rust or scale inside the cylinders of rescue apparatus was referred to on p. 25 of the First Report, where we touched upon certain of the risks of rusting. The Proto cylinders are particularly prone to give trouble from rust because of the narrowness and length of the passage from the cylinders to the reducing valve, and of the fact that that passage is all in steel. The danger with double-cylinder apparatus takes three forms: (*a*) The rust may choke the connection between the cylinders; (*b*) It may choke the pipe between the cylinder and the reducing valve, and (*c*) It may be ejected into the reducing valve and cause a stoppage there. In existing apparatus the second of these dangers is almost entirely limited to the Proto apparatus, and there the most likely part of the delivery neck to get choked is the part which is nearest to the cylinders, and, therefore (because of the curved shape of the neck), the most difficult to clean. This part is of narrow bore.

The third of the risks named above is avoided by the use of an effectual filter, placed immediately before the reducing valve. We have alluded to these filters in the First Report, pp. 25 and 26, where we mentioned the fact that in the Meco apparatus the filter has often been found to be absent, or only represented by gauzes having a mesh larger than the openings they were intended to protect. We recently met with a Proto apparatus similarly provided with a gauze which was obviously too coarse, and though in that instance the apparatus had been out of the makers' hands for three years, and the gauze may, therefore, have been changed during that interval, it was evident that it had been fitted in place by some person who did not realise the danger in question.

Since the First Report was written, evidence has accumulated bearing out the risk of the connection between the two Proto cylinders becoming choked by rust. Mr. W. Clifford relates* that during the recovery operations at Norton Colliery, in 1912, a certain pair of cylinders was found more than once to be partially run down when it came to be used; yet immersion in water failed to show any outward leakage. He noticed that the cylinders appeared to fill unusually rapidly at the pump, but that when they were closed and disconnected from the pump, the pressure slowly sank to about half the charging pressure, thus proving the presence in the pipe joining the cylinders of a plug of rust, which only permitted of a tardy equilisation of pressure. He states that since that time he has had several similar occurrences, and points out that the partial choking of the connection pipe is a danger, as the cylinders may be pumped up until the pump gauge shows a pressure of 2,000 pounds, but even then they would not contain a two-hours' supply of oxygen. The inference is clear: the oxygen should be held in one cylinder instead of two. But for the war and the fact that the existing official specifications as to the strength and weight of small cylinders have not yet been modified, this change would doubtless have been introduced already.

* *Trans. I. Min. Engs. LVI, p. 269.*

Digitized by Google

The most direct route of attack on the dangers attendant upon rust is to endeavour to prevent its formation. In the last Report we suggested coating the inside of oxygen cylinders, when new and after each annealing, with a varnish of a specified composition, that treatment being the most satisfactory we had then tried. We ventured to give the opinion at that time that experience might eventually point to some other method of protection as being superior to varnishing. Further experiment has, in fact, already led to the discovery of more effectual protective coatings, though none is so simple and easy to apply as varnishing. Certain of the processes named below may be known to the reader in connection with the protection of iron and steel structures of various kinds, but they have not hitherto been considered for preserving oxygen cylinders against corrosion. The present problem is, indeed, not an easy one, owing to high-pressure oxygen, especially when damp, being an intensely active chemical agent. The shape of the bottle, with its narrow mouth, enhances the difficulty of treatment and of the subsequent examination of the inside surface.

To obtain comparative indications as to the value of certain methods of protecting steel from attack by high pressure damp oxygen, eight mild steel bars were mounted in a cage and placed within a strong mild steel casing sufficiently large to hold the cage without any of the bars touching the sides of the casing. One of these bars was untreated, but the others had been given protective coatings, and to guard against failure through incorrect application, the bars (with the exception of those varnished and japanned) were obtained from the firms specialising in the methods in question. A pad of wet wool was placed in the casing to maintain the high-pressure atmosphere in a saturated state. Oxygen at a pressure of 80 atmos. was then introduced, and the casing kept closed for three weeks. After being withdrawn, the rods were arranged in the following order of merit, the first being the best:—

(1) *Tricolised.*—Although the surface of the bar had a tinge of rust here and there, the action had been very slight, and the protection proved far and away the best of those tried. The treatment is carried out by the Rustless Iron Co., of Keighley, Yorkshire; it consists of first heating the metal in a reducing atmosphere to a temperature not exceeding 900° F. (482° C.), and then subjecting it to the action of superheated steam, with the result that a coating of the magnetic oxide of iron is formed.

(2) *Sherardised.*—The result was good. The effect of the damp oxygen had been to form a slight amount of very fine white powder scattered over the surface. This powder seems to have baffled the chemist, and its exact nature is not yet known. Sherardising is carried out by Mr. Sherard Cowper-Coles, of Sunbury-on-Thames; it involves subjecting the metal, at a temperature of about 600° F. (316° C.), to the attack of zinc vapour, the surface being in this way zinc-coated. The inventor claims that the zinc forms a zinc-iron alloy at the surface, and the present test, when compared with that on a bar given an electrically-deposited zinc surface (*see* below), goes to support that claim.

(3) *Japanned.*—Here, again, the result may be termed satisfactory, though there were a few pimples of rust which had made their appearance through cracks or "pin-holes" in the japanned surface. A previous trial with japanned iron gave a result superior to this. Black japan consists of asphaltum mixed into a preparation of gum anime dissolved in linseed oil and turpentine; it is applied in a series of thin coats with stoving in between.

(4) *Coslettised and Pigmented.*—The rod was provided by the Coslett Company, Birmingham, having been coated by them, after coslettising, with a pigment whose nature was not specified. Local rusting occurred, the rust tending to grow in the form of round pimples which easily broke off, and which would be objectionable in an oxygen cylinder. Coslettising consists of coating the steel with iron phosphate by a wet process.

(5) *Varnished.*—In the instance under examination, the varnish, though it had not scaled, had allowed rust to break through at places. Though much better than

no protection, varnishing proved decidedly inferior to the above-mentioned methods, and especially to the first two. The varnish consisted of shellac dissolved in methylated spirit, venetian red being added to the solution.

(6) *Electrically-deposited Zinc.*—This method, which has proved superior in practice to sherardising as a protection against sea water, appears considerably inferior to the latter in the presence of high-pressure oxygen. Besides the deposit of white powder remarked upon in the case of (2), there was a considerable growth of red rust which had broken through the protective covering. The treatment is evidently of little or no service for the purpose in view.

(7) *Coslettised.*—The process gave very little protection. The same result had previously been arrived at with rods coslettised by Dr. Desch, Glasgow, and kindly sent by him for trial.

(8) *Untreated Rod.*—There was most marked rusting.

The problem of the protection of oxygen cylinders against corrosion cannot yet be considered as solved, and we put forward these results more by way of a progress report on the matter than as offering a final settlement. The Oxygen Research Committee of the Department of Scientific and Industrial Research, as well as ourselves, continue to devote attention to the problem. A Chesterfield light cylinder (*see* p. 42) was tricolised and afterwards hydraulically tested. It was found to have suffered no diminution of strength; but although it had received an excellent outer coat of the black oxide, the inner surface left much to be desired. A considerable modification of the method adopted at the works will be needed to treat gas cylinders successfully. As the coating of magnetic oxide is most difficult to remove, care must be taken either to protect the screw at the bottle neck during treatment by screwing in a tube, or, in the case of a new cylinder, to cut the screw after tricolising; otherwise trouble will be encountered when the valve comes to be sweated into place.

Besides the methods discussed above, we have experimented on the action of high-pressure oxygen on the hard enamel coating (virtually a glass) familiar to users of culinary vessels. The protection offered was excellent; but the liability of the covering to crack (especially during the expansion of a bottle when being charged), and the difficulty of obtaining a perfect coat of that kind inside a cylinder, led to the idea being abandoned.

The Drying of Oxygen.—The rusting problem may be attacked from another side: an endeavour may be made to dry the oxygen forced into the cylinders of rescue apparatus. It has been repeatedly observed that the cylinders coming from the various works of the British Oxygen Company are wet, and on some occasions, particularly in the Newcastle and Doncaster districts, to such a degree that water is discharged from a storage cylinder when it is held mouth downwards. The Company tests the cylinders hydraulically, and it is to be regretted that too little care is exercised in clearing the cylinders of water after that test. They should, indeed, be thoroughly dried before again being put into service, and, to avoid disturbing the valve in so doing, the drying may preferably be performed by warming the cylinder while it is in connection with a vacuum pump.

A precautionary measure which can be carried out at a rescue station, and which we strongly recommend, is that of introducing a drier between the oxygen pump and the cylinder being charged by the pump. Even if perfectly dry oxygen were obtainable from the manufacturers, it would often carry water from the pump owing to the common use of a mixture of water and glycerine for lubrication. Fig. 2 illustrates a simple drier, designed by Mr. D. Penman and intended for use with a small oxygen pump. It has been installed for several months at the Edinburgh station, where it gives satisfaction. It was tested hydraulically at 200 atmospheres before being put into use. The case and cover are of mild steel, the joint between the two being made secure by a lead washer. The drying medium, whether coarse caustic soda granules, caustic soda balls (a recent product of Messrs. Crosfield's), or fused calcium chloride lumps, is contained in an inner sheet-metal container. A plug of glass-wool (not cotton-wool) at the discharge side prevents particles of

Digitized by Google

the drying substance being carried into the cylinder. The bottom portion of the inner case is arranged as a trap for any liquid that may collect. The drying chemical should be changed at regular intervals, which should be shortened if, on

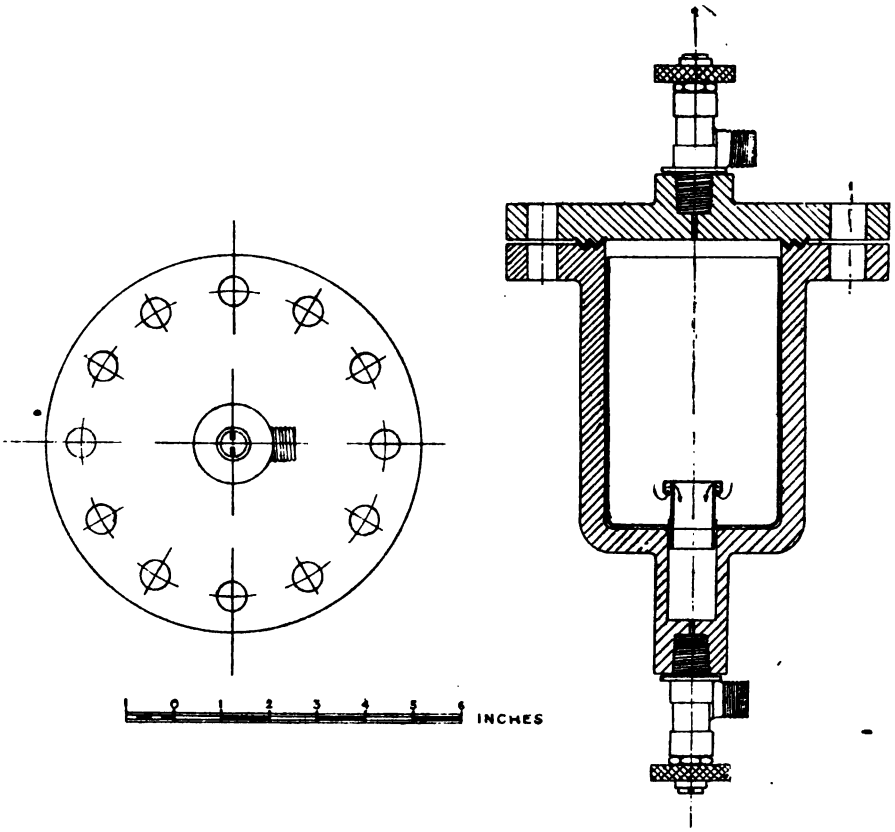


FIG. 2.—Drier for use with Oxygen Pump.

opening the case, liquid is found within. The drier is provided with two stop-cocks to avoid wasting the compressed oxygen which it holds after a cylinder has been charged.

The Choking of Reducing Valves by Water.—The entry of water into the cylinder of a rescue apparatus is not only objectionable from the point of view of the corrosion it may set up; if ejected into the reducing valve, it is not unlikely to cause a stoppage. Mr. J. Cooper, then instructor at the Edinburgh station, reported a sudden cessation in the oxygen delivery of a Meco apparatus which was being used by one of a colliery brigade during an underground practice. On returning to the station the apparatus was found to function properly. It was overhauled, but nothing unusual was discovered other than a few drops of water in the reducing valve. A similar occurrence with a Proto apparatus has been recently recorded by Mr. F. P. Mills of Newcastle.* We made a series of experiments on the influence of water in the Meco reducing valve. It was found that the mere fact of the compressed oxygen in the cylinder being saturated did not lead to choking, if the reducing valve itself did not contain water. That result was to be expected, since the oxygen, though saturated at high pressure, would be very dry after expansion to low pressure.

A stoppage, or partial stoppage, could generally be produced, if the reducing valve contained water, by turning the valve over, and particularly by turning from the

* *Trans. I. Min. Engs. LVII, p. 150.*

Digitized by Google

normal position (where the diaphragm is uppermost) to the reverse position. The following is a transcript of the laboratory record of one of these tests:—

> "A small quantity of water was placed in the reducing valve, the cylinder pressure being 100 atmos. After the oxygen had been flowing normally for a few seconds, the reducing valve was suddenly turned upside down. The flow immediately became less, and continued slowing down until it nearly stopped. Then it came away with a rush, and kept normal for a time. After about two minutes or so, the flow began again to slow down and the above sequence repeated itself. This was done several times with the same results. In no case was complete stoppage obtained."

The fine oxygen inlet enters the reducing valve at the summit of a cone-shaped projection on which rests the vulcanite valve. So long as the reducing valve is kept in the normal position, any water lodging within the valve box will lie round the base of the conical projection; but when the valve is reversed, the water will run down the cone, which will act as a dripping point. In the latter position, therefore, the water is directed into the oxygen jet, and temporary freezing will probably result, with total or partial stoppage of the flow. After a little time a frozen jet will thaw again and let the gas through "with a rush"; the temperature will then again fall and another stoppage or partial stoppage follow. Freezing at the mouth of the jet, whether of water ejected from the cylinder or of water lurking in the reducing valve box and dripping into the jet in the manner stated, is probably due to the cooling influence of rapid evaporation augmented by the Joule-Thomson effect, the ice collecting under the vulcanite and blocking or throttling the inlet passage. We were unable to get a stoppage when the whole reducing valve was immersed in hot water.

If the reducing valve box contain so much water that it is forced through the orifice on the discharge side of the box, it will, of course, lead to a momentary cessation of supply until it has been expelled. The pressure-difference on the two sides of the discharge opening are, however, small, and the cooling effect, therefore, negligible; freezing at that point will thus be a most rare occurrence.

A highly dangerous condition arises when water from the cylinder enters the inlet orifice of a reducing valve, when that opening is already partially choked with rust particles. A sufficient stream of oxygen may emerge through the obstruction so long as it remains dry; but a total and long-continued stoppage may immediately follow upon the entry of water into the duct.

The more completely the results and dangers of allowing water to enter an oxygen cylinder are studied, the greater appears the need for adopting every precaution to prevent it getting in.

Rescue Apparatus Valves.—The abolition of the injector in rescue apparatus (a recommendation of our First Report) will render the valves of all such apparatus altogether responsible for the proper direction of the air in the circuit.

A good valve should close tightly, open readily, have little "slip"* and, when open, offer little resistance to the flow of air through it. It should also be simple, easily examined and easily changed, and should work equally well when held in any position.

With self-contained apparatus, the effect of slip is rather more important with the exhalation than with the inhalation valve. A small slip at the latter means that a portion of the air last drawn into the lungs gets past the valve, and is re-inhaled on the next breath; that air, however, contains relatively little carbon dioxide. The same slip at the exhalation valve results in the return of the same volume of exhaled air, but this time that volume comes from the end of the previous expiration and contains relatively much carbon dioxide. With apparatus of the respirator type, or the mouthpiece-and-tube appliances described on p. 39), the slip of the expiratory valve is altogether more serious than that of the inspiratory valve; if there should be a slip at the latter, all that happens is the re-inhalation of a

* If 100 volumes pass through a valve and it let 10 pass back again owing to sluggishness in closing it is said to have a 10 per cent. slip.

Digitized by Google

little CO_2 on the next breath, but if there should be slip or leakage at the former, some of the poisonous atmosphere passes direct into the lungs at every in-drawn breath.

The apparatus we employed to measure the slip of valves—or, more truly, slip *plus* leakage—is illustrated by the accompanying figure. *A* is a pulsator, designed by Drs. Haldane, Meakins and Priestley for another purpose, and consisting of a rubber concertina which can be made to move a definite distance between stops. It takes the place of the lungs, expiring and inspiring a definite volume per stroke at any desired rate. By setting the stops nearer together or wider apart, shallower or deeper breathing can be simulated. *B* is a metal mouthpiece, fitted with identical inlet and outlet valves of the kind being tested. Air-tight bags, *C* and *D*, are attached on the inlet and outlet sides of the mouthpiece, respectively. On starting a test, *C* is filled through a dry meter with a known volume of air; its stop-cock *c* is then shut, and the bag connected in the manner shown in the figure. *D* is completely emptied. The two stop-cocks being now opened, the pulsator is caused to respire at the rate required for a timed period, during which the number of strokes is counted. Both stop-cocks are then closed, and the volume in the bags ascertained by emptying each through the meter. If the measurements were correctly made and there was no leakage to the outer air during the test, the volume lost by *C* would have been gained by *D*. Had the valves been perfect, that volume would be equal to the displacement of the pulsator, multiplied by the number of double strokes; the extent to which that volume falls short of the latter amount evaluates the slip of the pair of valves. The displacement per stroke of the pulsator with each setting of the stops was carefully ascertained by causing it to respire a counted number of times into a bag fitted with a three-way tap. The tap was worked by hand so that the bellows drew air from outside during inspiration and blew it into the bag during expiration. This "blank" experiment was in each case repeated two or three times. In some of these tests a single-acting piston pump was used instead of the "concertina."

The mean of several tests of each pair of valves in each of the stated positions in entered in the seventh column of Table 7.

It can be shown that with any single-acting pump (and here the lungs behave as such), if the delivery valve has a slip of S_1 (expressed as a fraction) and the inlet a slip of S_2, the slip, S, of the pair is

$$S = \frac{S_1 + S_2 - 2S_1S_2}{1 - S_1S_2}.$$

In the present case the tests were conducted on pairs of identical valves, or $S_1 = S_2 \doteq s$; therefore:

$$S = \frac{2s}{1 + s}.$$

Values for S having been determined by experiment, those for s were computed from this formula; they are to be found in the eighth column, Table 7. When S is not more than ·08 or ·09 (8 or 9 per cent.), it is close enough for practical purposes to take $s = \frac{S}{2}$ but larger slips must be calculated from the formula stated.

To compare the resistance of passage of valves, it is necessary to select some rate of flow at which the resistance can in every case be measured. In common with the Anti-Gas Department of the Ministry of Munitions, the standard of 3 c.ft. (85 litres) per minute was selected for the purpose. That rate will be realised at the middle of an expiration by a person breathing 30 to 35 litres of air per minute.

Of the valves named in the table below, the mica valve is too well known to need illustration. The Thiry valve, first described in 1865, is that used in the Tissot apparatus. It is a clack of thin brass, with a brass seat. It is hinged at the top and is set at 45 degrees to the axis of the tube. Fig. 4 shows two such valves in a Tissot mouthpiece. When the head is in its normal position or turned to the left, the weight of a valve assists it to close, and in those positions the slip is small. When the head is turned to the right, the weight tends to keep the valve open and the slip is large; while if the wearer of the apparatus is facing down, the slip, as

Digitized by Google

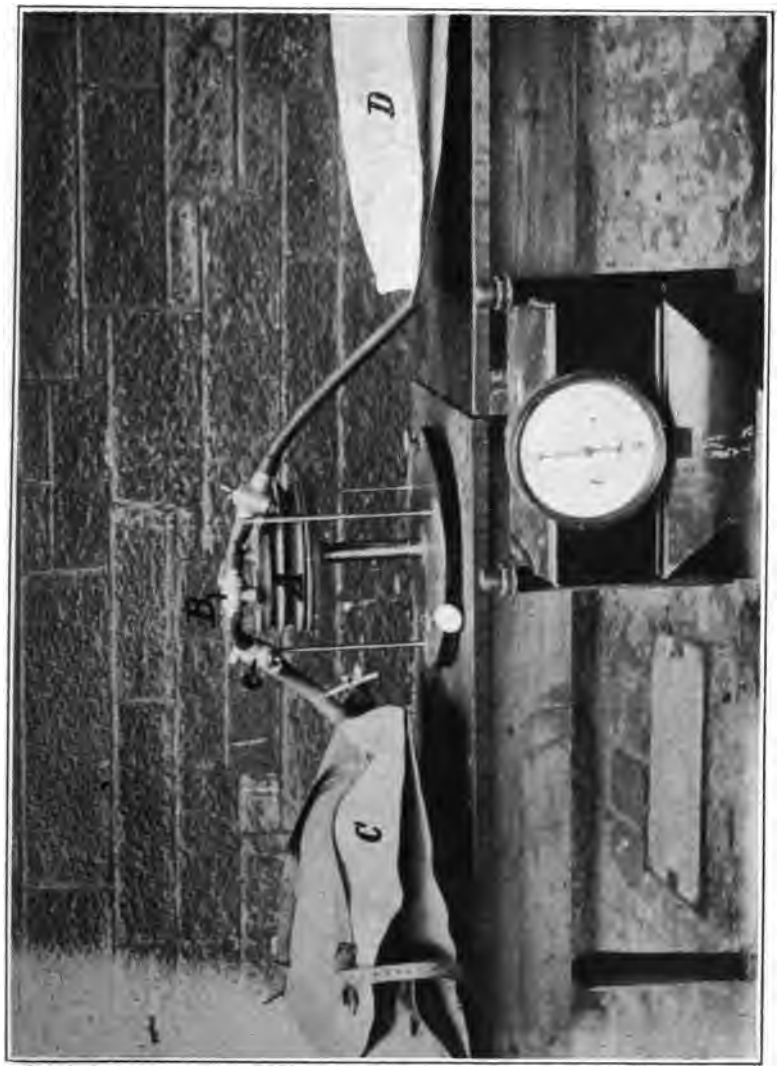


FIG. 3.—Apparatus for ascertaining Slip of Valves.

Digitized by Google
UNIV. OF MICH.

Digitized by Google

Digitized by Google

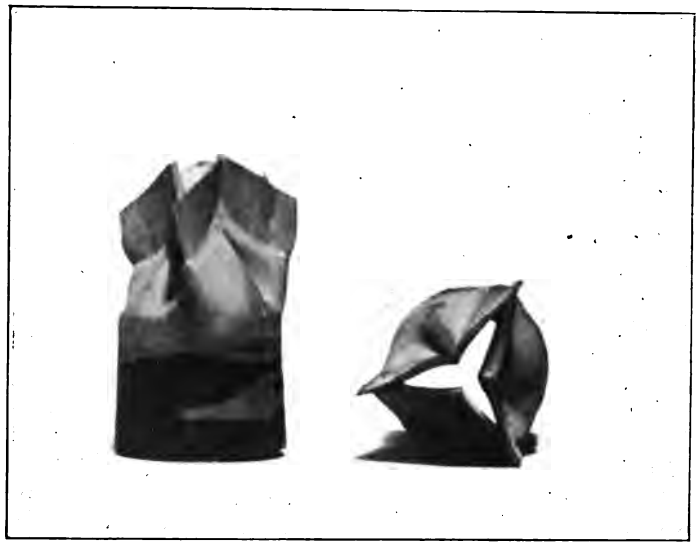


FIG. 5.—Split-tube Valve.

FIG. 6.—Rosling Valve, shut and open.

UNIV. OF MICH.

Digitized by Google

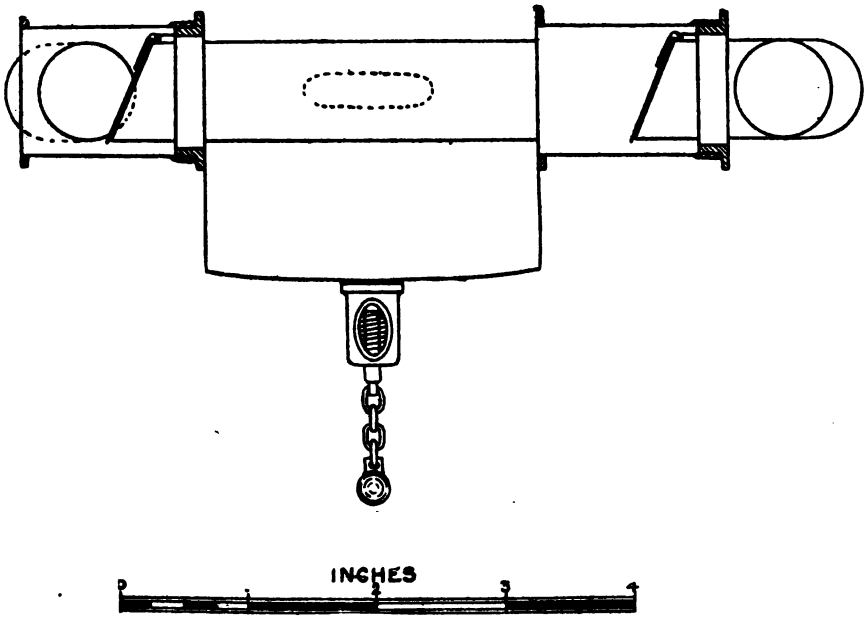


FIG. 4.—Tissot Mouthpiece.

the table shows, has an intermediate value. Notwithstanding the narrowness of the tube in which it works, its wide passage-way when open, taken in conjunction with the fact that it allows of almost a straight-line flow along the tube, reduces the resistance of this valve to an unusually low figure.

The rubber disc valve was one taken from an army box respirator where it acted as inlet. For test purposes it was placed in a metal case attached to a 1-inch tube. The valve is a disc of thin rubber, pinned down at its centre to a grid having six openings through it. Though not particularly tight, its behaviour is not so affected by its position as are those of the mica and Thiry valves. A similar, though smaller, valve has been tried for the Weg apparatus. The so-called split tube valve (Fig. 5) was made by us in the hope of getting a reasonably slipless valve permitting of a straight-line flow through it. Such a valve could have been mounted in a tube but little larger in diameter than that of the rest of the circuit. It failed, however, owing to its high resistance.

The Rosling square-rubber valve (Fig. 6) is the invention of Lieut. Rosling of the Anti-Gas Department, and was adopted for box respirators by that Department towards the end of the war. In the larger size made for us by the Isleworth Rubber Company, it comes nearer to the ideal than any we have examined. Its slip is very small, its resistance is low, and it is a matter of indifference which way up it may be. The experience of this valve gained by the Anti-Gas Department testifies to its durability in service. The only drawback to its application to rescue apparatus—and it is not a specially serious one—is that it requires to be mounted in a valve-box of diameter considerably larger than that of the tubing leading to and from it.

The last valve on the list (the Mueller valve), though inapplicable to rescue apparatus, is useful in respiration experiments if the subject is stationary, and it has been shown to give satisfactory results for that purpose.* The diagram (Fig. 7) is of a glass Mueller valve used by us, and of a size suitable for heavy breathing. The inflow to the valve is by the glass tube *A*, which dips about half-an-inch below the surface of the water in the jar. The water prevents any return of air up *A*, but nevertheless there is a small rise of liquid in that tube due to the resistance of

* T. M. Carpenter, *Comparison of Methods for Determining the Respiratory Exchange of Man* (Washington, 1915), p. 195.

Digitized by Google

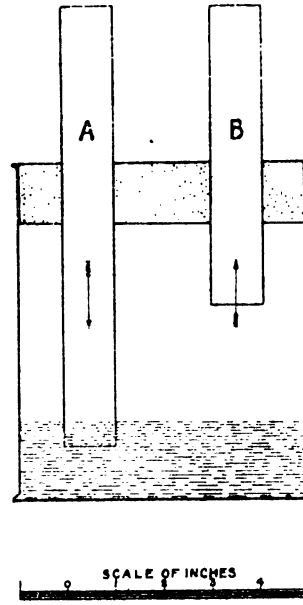


FIG. 7.—Mueller Water Valve.

the companion valve when the latter is passing the air, and the volume of water raised in the tube evaluates the slip. Of those tested, the Mueller is the **only** valve whose percentage slip increases with the volume delivered.

TABLE 7.

Slip and Resistance of Various Valves.

Type of Valve.	Diameter of Valve.	Diameter of Tube leading to Valve.	Position of Valve.	Litres of Air Breathed per minute.	No. of Breaths per minute.	Percentage Slip per pair of Valves (measured).	Percentage Slip per Valve (calculated).	Resistance per Valve to passage of 3 c. ft. per minute.	Remarks.
	Ins.	Ins.						Ins. of Water.	
Mica disc, Douglas Respiratory Apparatus.	Disc, 1·1 Seat, 1·0	1·1	Right way up.	43·8	20	5·5	2·8		Weight of valve helps to close it.
			On side	43·8	21	8·2	4·3		
			Do.	19·5	9	9·8	5·2		
			Do.	12·5	6	92·7	86·4	0·375	The valve was found to have jammed so that it could not close.
			Do.	62·0	29	76·0	61·3		
			Upside down.	50·0	22	24·0	13·6		The valve falls away from its seat.
			Do.	8·8	4	63·6	46·6		
Mica disc (Douglas) with spring.	Disc. 1·1 Seat, 1·0	1·1	Right way up.	43·8	20	8·0	4·1	0·55	The same valve as above, fitted with a light control spring.
			Do.	11·9	5	15·8	8·6		
			On side	43·8	20	6·0	3·1		
			Upside down.	35·0	18	10·0	5·3		
Mica disc, Proto Apparatus.	Disc, 1·1 Seat, 1·0	0·75	Right way up.	34·0	12	1·75	0·9	0·7	
			Reversed	34·0	12	25·0	14·3		
			On side	34·0	1	12·5	6·6		

Digitized by Google

SLIP AND RESISTANCE OF VARIOUS VALVES.

Type of Valve.	Diameter of Valve.	Diameter of Tube leading to Valve.	Position of Valve.	Litres of Air Breathed per minute.	No. of Breaths per minute.	Percentage Slip per pair of Valves (measured).	Percentage Slip per Valve (calculated).	Resistance per Valve to passage of 8 c. ft. per minute.	Remarks.
	Ins.	Ins.						Ins. of Water.	
Thiry clack.	0·8	0·7	Right way up.	40·0	20	6·0	3·1		Weight of valve helps to close it.
			Do.	22·5	9	9·0	4·7		
			Wearer facing downwards.	12·0	6	37·0	22·7	0·25	Weight of valve has no influence.
			Do.	44·5	21	17·0	9·3		
			Wearer lying on his side.	45·0	21	53·8	36·8		Weight tends to keep valve open.
Rubber disc.	1·5	1·0	Right way up.	51·0	24	16·0	8·7		
			On side	47·7	22	16·8	9·2	0·55	
			Upside down.	41·8	20	26·4	15·2		
Split tube.	1·0	0·9	Pointing up.	44·0	15	7·8	4·1	3·65	Owing to high resistance not tested further.
Rosling square (small).	1·25 (across corners).	0·65	Upright	37·6	18	4·0	2·0	0·75	
			On side	26·2	11	10·2	5·4		
Rosling square (large).	1·5 (across corners).	0·85	Upright	37·7	17	2·5	1·25	0·35	
			On side	44·5	20	2·0	1·0		
			Upside down.	25·0	12	2·2	1·1		
Mueller water.	—	1·1	Normal	26·2	12	3·0	1·5	1·0	Tube dipping 0·6 in. under surface of water.
			Do.	65·7	30	5·5	2·8		

When working the proper way up, when the valve's weight helps it to close, the mica valve is thoroughly efficient and its slip is negligible; but if called upon to function upside down, in the manner of the exhalation valve of the Proto apparatus, the slip (as the Table shows) may be serious. It is useless to cut down dead-space if one of the valves may let back a large part. of the volume forced through it by the lungs. The effect of re-breathing expired air is to stimulate the respiration (*see* p. 9): thus, the lungs automatically do their best to close a refractory valve; but should the CO_2-absorption be imperfect, slip becomes a serious matter and may contribute largely to the distress of the wearer, and, in a more extreme case, to his collapse. The results set forth in the table reveal a still more serious state of affairs when the large mica valve of the Douglas respiratory apparatus is resting on its side. Now and then, as shown in the second and third lines of the Table, the slip in that position may not be excessive; but as likely as not the valve may get caught between two of the wires of the cage in which it is usually mounted (*see* the fourth and fifth lines), and then it is virtually out of action. Though we have no evidence of the mica valve giving trouble through sticking in existing apparatus, and although the Douglas appliance was not meant to be used on its side or upside down, the examples show that there may be risk with mica valves unless they are carefully made.

The mica valve of the first section of the Table was fitted with a light spring to assist it in closing. This addition brought about an improvement in regard to slip in the inverted position, and reduced, to some extent, the chance of jamming when the disc was working on its side. These advantages were secured, however,

at the expense of greater complication and resistance, and it doubtful if modification will commend itself to many.

As might be expected, the tests of valves indicate that the percentage slip with valve in any given position is less with hard than with quiet breathing. The latter is a fortunate one.

Nose Clips.—The problem of devising a nose clip which will provide reasonable security against accidental displacement has occupied considerable attention during the last few months. A pamphlet was issued by the Research Department early in 1919, in which there were illustrated three types of nose clip claiming increased security. The variety of screw clip shown in Fig. 16, and adopted for the Briggs apparatus, is an improvement on a clip described in that pamphlet. Figs. 8 and 9 are reproduced from the pamphlet, and illustrate respectively a spring clip which has given satisfaction at the Swansea Rescue Station, and a German screw clip similar in type but heavier and less secure. Thanks are due to the Superintendents of the Swansea and Crumlin rescue stations for calling attention to these types. In each of these latter varieties the bow of the clip passes loosely round the metal portion of the mouthpiece. In that of Fig. 9 a piece of elastic draws the two legs of the clip together. Mr. G. L. Brown has also devised a spring clip similar in principle to that of Fig. 8, but allowing of some variation in the distance between the centre of the pads and the metal mouthpiece, in this way providing for differences in the length of the upper lip.* If a form of clip be adopted where the bow encircles the metal part of the mouthpiece, it will be advisable to use a mouthpiece attachment similar to that of Fig. 16, which practically precludes the possibility of the mouthpiece falling out, for, with nose clips of this character, the removal of the mouthpiece entails the displacement of the clip. Another variety of spring clip, possessing a high degree of security, has been evolved by Mr. Hopwood of Altofts. In a slightly modified form it is shown in Fig. 10, where it will be seen that the clip can be adjusted vertically by slipping it along a leather band. The strap also prevents the clip being knocked off.

Providing that it is held securely, the screw type of clip has the advantage of greater comfort. It is worth observing that an uncomfortable clip is dangerous in that, during a prolonged spell of work with the apparatus, the pressure on the nose becomes almost intolerable, and the temptation to take off the clip for a while is most difficult to resist.

Face Masks.—During 1918, the Anti-Gas Department (Ministry of Munitions) devoted considerable attention to face masks in connection with box respirators, in order to see if a sufficiently tight joint could be secured to allow of the nose clip being dispensed with, and masks were evolved by the Department incorporating certain novelties in construction and material. Late in the year, Lt.-Col. Raper and Major Lambert kindly described to us the course of the experiments, and suggested a union of forces to attack this and kindred problems.

We tested two army masks known as the American "Akron Tissot" and the British "Tissot" mask. They endeavour to make a gas-tight seal along practically the same circuit of the face as the old-fashioned rescue apparatus "helmet," and, owing to the greater flexibility of the material from which they are constructed, and to a more exact regard to the facial contour, they certainly achieve greater tightness at the face joint than did the helmet. At the same time, the results obtained (as will be shortly seen) indicate a degree of security inferior to that of the mouthpiece and nose clip. This, together with the further drawback of increased dead space, is sufficient to condemn these masks.

A simple outfit for testing masks consists of a cubical box with windows, a side door, and an opening in the bottom through which the wearer of the mask can thrust his head. A curtain of cloth, or wash-leather, round the bottom opening can be tucked round the wearer's neck, or buttoned under his coat, to prevent the gas escaping too rapidly. An absolutely irrespirable atmosphere is created in the box by blowing in a little SO_2 from a syphon. The box is conveniently slung from the ceiling, so as not unduly to impede the man's movements, and an ergometer (p. 54) placed under the box makes it easily possible to give

* *See Coll. Guard.*, Feb. 27, 1920, p. 588.

Digitized by Google

FIG. 8.—Spring Nose-clip used at Swansea.

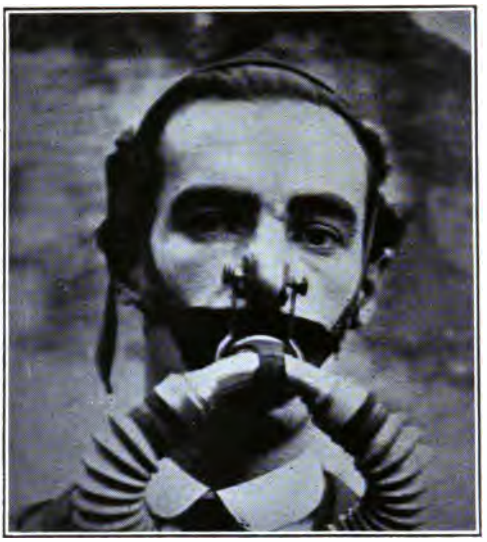


FIG. 9.—German form of Screw Nose-clip.

FIG. 10.—Hopwood's Spring Nose-clip.

UNIV. OF MICH.
Digitized by Google

Digitized by Google

him hard work (and so promote heavy breathing) while he wears the mask. Inhalation and exhalation tubes passing out of the box carry air to and from the mask. Resistance to breathing may be introduced by throttling these tubes, and its amount indicated by water gauges. Where so much depends on the shape of the face, it is evident that a mask should be tried on several persons, and that extremes of facial cast should be sought rather than avoided.

The clean shaven man presents obvious advantages when dealing with face masks; no matter how good the mask may be, it does not make a secure fit on a bearded or unshaven face, and a long moustache is also undesirable. These are limitations from which the mouthpiece is free.

The American and British Tissot masks were tried on six persons, mostly clean-shaven. The former mask proved the better. It was tight in all cases when the subject did no work, even with resistances such as ± 8 ins. of water. The mask lifted off the face when expiring against resistance, and allowed air to escape round it; but, when the subject was at rest, it closed back, valve-fashion, at the end of expiration and made a tight joint. With the majority, the American mask was tight when the subject did work on the ergometer, though one man was distressed by heat; but in certain cases, the slight tugging of the connecting tubes due to the short, sharp movements of the head while working, led to gas being drawn in, even with relatively low resistance like ± 2 ins. of water. It became evident that the tubes leading to a face mask must be flexible in the highest degree, or that they must be arranged as in the Weg apparatus (*see* First Report, p. 10).

The British Tissot mask was tested on five persons. It was found to let in gas with resistances exceeding ±3 ins. of water when the men were resting, and was, therefore, not tried further.

A few experiments were made with the American mask to illustrate the effect of dead-space. By withdrawing air-samples, it was found that, even after inspiration, an appreciable proportion (usually about 0·4 per cent.) of CO_2 remained in the mask, representing a part of the last expiration not swilled out by the inflowing fresh air. As was to be expected, the dead-space held, after expiration, with different subjects and different degrees of exertion, from 3·3 to 5·9 per cent. of CO_2. When the volume of air drawn in per minute was metered, first using the mouthpiece and then using the mask, it was found that the CO_2 in the dead-space of the latter caused an average increase of 16 per cent. in the lung ventilation with subjects doing 5,000 ft.-lbs. of work per minute.

Though our experience of face masks down to the present has not been specially promising, it cannot be denied that a thoroughly secure mask (if such is within the bounds of possibility) would be a valuable adjunct to rescue apparatus. It would allow of the user speaking to his companions without risk; it would enable a telephone connection to be maintained between the leader of a party and the base; it would also permit of breathing through nose and mouth, and do away with the noseclip, besides being probably more comfortable than the mouthpiece.

Useful work on masks is proceeding at the Altofts and Wemyss rescue stations, and at the latter the men have been instructed for a considerable time in the use of the telephone, in which the transmitter is attached to the front of the leader's mask, while his receiver is strapped to one ear. The second in command also has a transmitter fitted to his mask and carries a receiver in his pocket. Should the leader collapse during work, the second man can quickly connect himself to the battery box and thus to the base. Without doubt, such a manner of communication is preferable to signalling, and ready means of communication has a highly beneficial effect on morale; yet all such considerations must remain subservient to the question of security of the mask. The fact remains that we have yet to find a mask which will adapt itself to all faces (leaving bearded ones out of account) and which will make a thoroughly tight joint in the circumstances attending actual service with rescue apparatus. In our own attempt to solve the problem, we have worked upon a line suggested, and to some extent developed, by the Anti-Gas Department, the joint against the face being made by a shaped ring of rubber sponge. Owing to the difficulty of getting supplies, we have, however, not progressed sufficiently far with

Digitized by Google

this type of mask to enable a conclusion to be reached; but we hope to deal with the matter in the Third Report.

We have here considered the face mask as a possible substitute for the mouthpiece, and not as an addition to the mouthpiece. The army box respirator, as is well known, includes both mask and mouthpiece. Such a combination may occasionally be useful with rescue apparatus. For example, when it became evident at the Front that the Germans were using lachrymatory charges in mining operations, the exploration of galleries after a "blow" was often carried out with Salvus apparatus fitted with the mask, mouthpiece and noseclip of the box respirator.*

Flow Gauge for Proto Apparatus.—Fig. 11 is a section of a flow gauge designed for use with the Proto apparatus. The mode of action is the same as that described

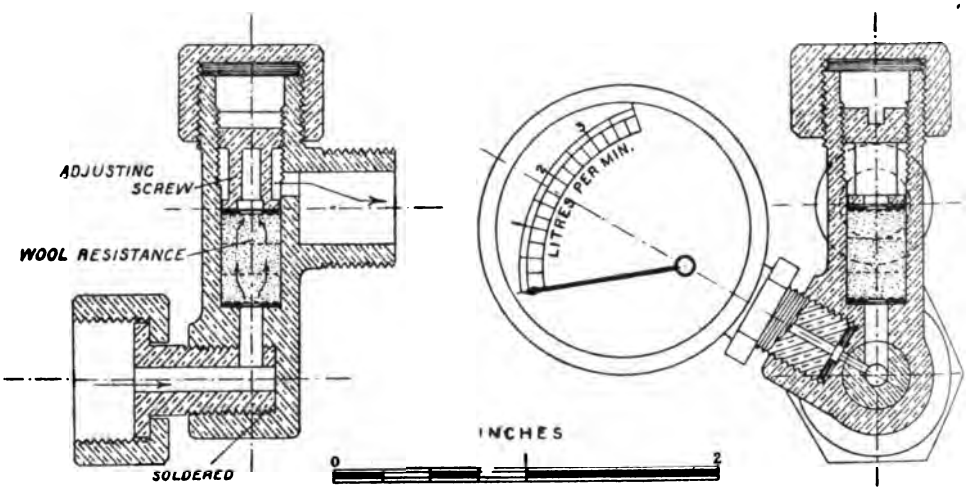


FIG. 11.—Flow Meter for P♀ to Apparatus.

on p. 45 in connection with the Briggs apparatus, and like the latter, it is intended to indicate continuously the flow of oxygen from the reducing valve. The position of the device when attached to the apparatus is shown by the photograph, Fig. 12, where it will be seen that the small circular gauge, while lying close to the wearer's body, is easily within his view. Prior to attaching the device, the small orifice on the outflow side of the reducing valve is removed, since the resistance of the plug of cotton wool takes the place of that of the orifice. The principle and mode of adjustment of the device is described on p. 45. Though this type of meter was first used with the Proto apparatus in the manner here shown, it does not lend itself so well to that apparatus as to Dr. Briggs', since the discharge of the by-pass is in the former case on the in-flow side of the resistance, while in the latter apparatus it is arranged to be on the out-flow side.

Warning against the use of the Army Box-Respirator, Eeds Smoke and Gas Helmets, and similar Appliances for Mining Purposes.†

There is an erroneous belief, especially among demobilised men returning to the mines, that the army box-respirator, which has proved so excellent a protection against poison gas, would safeguard a man equally well if he were attempting to penetrate a noxious atmosphere underground. An appliance known as the Eeds Helmet is being advertised in the mining technical papers, and as it is recommended by the makers for use in mines, it is necessary in the interests of

* Lt.-Col. D. Dale Logan, *Trans. I. Min. Engs.* LVII, p. 235.

† This warning, in substantially the same terms, was issued to the technical press under date 26th May, 1919.

Digitized by Google

FIG. 12.—The Flow Meter in position, Proto Apparatus.

UNIV. OF MICH.

Digitized by Google

Digitized by Google

safety to warn mine managers and superintendents of rescue stations that this appliance, like the army respirator, is inapplicable for mining purposes.

In the Eeds appliances, the air is intended to be drawn through a sponge filter which is damped with water or other solution. Apart from the fact that the high resistance of the filter—much increased by saliva—makes it impossible to carry out physical work while using the Eeds helmet, such an apparatus is wrong in principle if intended for service underground. The main risk in attacking a mine fire, or in penetrating workings after an explosion, is due to carbon monoxide. A second risk, which is seldom of importance at the surface, but which cannot be disregarded in mines, is that an atmosphere may be entered which contains an insufficient amount of oxygen to support life.

Neither the army respirator nor the Eeds appliances give the least security against either of these dangers, and if they be used in mines, the result may be fatal to those wearing them. The army respirator, and, to an inferior degree, the Eeds helmet, will stop smoke; for that reason they would give a person ignorant of the real danger a feeling of security when entering smoky air, and thus would add to the probability of his being overcome.

This type of breathing appliance, therefore, cannot be looked upon as a substitute for self-contained rescue apparatus.

The Smoke Helmet and other Hose-pipe Apparatus.—Limited in scope though the smoke helmet must necessarily be, it has proved itself of service on several occasions, as, for example, in fighting fires after the Senghenydd explosion, 1913, and at the Ashington Colliery in the same year. In the latter case the helmet allowed men to use water-hoses on the fire and enabled them to open separation doors in foul air.*

The possibility of using compressed air (when available) as a means of feeding helmets has received little attention; yet on one occasion, namely, in the attack on a large timber fire in the Homestake Mine, South Dakota, U.S.A., in 1907, the method proved successful. In that instance those at work with the water-jets were provided with leather helmets which received air from a compressed air main through small-bore hoses.†

The ordinary smoke helmet, of which there are large numbers at rescue stations and mines, is a modification of the diver's apparatus; like the latter, it completely covers the head of the wearer, and the imitation is in many cases carried so far that a blow-off valve is provided on the helmet when the loose joint round the shoulders makes that valve altogether superfluous.

The smoke-helmet in its usual form has the following special drawbacks and dangers:—

(1) The flexible hose is vulnerable; it may be cut by a tub-wheel or by a falling stone; a heavier fall, though it may not block the road, may flatten the pipe, or hold it and so trap the helmet-man.

(2) A fall completely blocking the road between the fire and the base spells disaster, as the helmet-man is unable to use any other way of escape, should one exist.

(3) The management of the hose by the helmet-man is not easy, owing to its weight and cumbrous character; these features are such as to limit the range, under the conditions usually obtaining in the mine, to about 50 yards from fresh air. If the man is carrying tools or material, he is still further incommoded by the tube, and the practicable range is still further reduced.

(4) In such work as building an earth stopping, where tubs have to be run in, the tube becomes a hopeless encumbrance, and the risk of it being cut is much increased.

(5) Rapid escape is difficult; if the helmet-man tries to get back to fresh air dragging the pipe behind him instead of coiling it up as he comes, there is a

* F. L. Booth: *Underground Fire at Ashington Colliery and the Use of two Smoke Helmets. Trans Nat. Assn. Coll. Mans. XI, p. 208.*

† *Engineering and Mining Journal (New York), March 28, 1908.*

Digitized by Google

considerable chance of the hose getting caught. Again, there is the possibility in that case of him returning on the wrong side of a line of centre-props.

(6) The hissing of air entering the helmet may prevent the wearer hearing the warning noises given by a roof under movement.

(7) Vision is limited: with some helmets extremely so; and it is thus difficult for the wearer to make a proper inspection of the roof.

(8) Two persons are required for each smoke helmet as against one with each self-contained apparatus.

The first five of these disadvantages are inseparable from the use of a hose, and cannot be removed except by giving up this type of appliance; but it seemed to us probable that the last three could be avoided by substituting a mouthpiece attachment for the helmet, and by causing the wearer to draw his air supply through the pipe instead of having it forced to him by a bellows or mechanical blower. Although the modification introduces other demerits, namely, negative pressure, a more limited range of exertion and reduced cooling of the face and head—drawbacks which we have no desire to minimise—the proposal proved feasible. It really amounts to the revival of the oldest form of breathing apparatus intended for use in mines, for a hose and mouthpiece appliance (with inhalation and exhalation valves) was described in the *Universal Magazine* of 1752.

No difficulty will be found in drawing air through a mouthpiece and hose, providing no work is being attempted. The lungs are quite capable of sucking seven or ten litres of air through a ¾ in. bore tube 30 or 50 yards (and even more) in length, the expired products being discharged direct to the atmosphere; but when exertion is involved and the volume needed increases perhaps six-fold, it becomes physically impossible to obtain the air by drawing it directly from the tube. While they are powerful enough to maintain a flow of, say, 40 litres per minute along such a pipe when that flow is uniform, the lungs are not sufficiently strong to induce that volume to pass in the intermittent or spasmodic manner which is their natural way of moving air. Evidently, then, if the plain mouthpiece and hose appliance is going to be of practical use, it is necessary to introduce between the lungs and the tube something having the function of the air-vessel of a ram pump, namely, that of converting a pulsating into almost a uniform flow.

Before describing the means adopted to change the manner of flow in the hose, it is advisable at this point to interpolate an account of certain experiments made on the flow of air through a ¾ in. bore smoke-helmet tube 90 ft. long. The purpose of the experiments was to ascertain the relation between the volume of air carried by the tube and the pressure required to create the flow, both when the delivery was steady and when it was fluctuating. The results allowed of calculations being made on the power expended in the two cases in drawing a given quantity of air per minute through the pipe. The results may be of use, we think, to those dealing with compressed air transmission, as well as in their relation to the smoke helmet problem. Air was caused to flow through the tube from a closed tank, 3 ft. by 2 ft. 6 ins. by 1 ft. 6 ins., from which it was displaced by water. The rate of rise of the water surface, as indicated on a gauge glass, determined the number of cubic feet of air passing along the tube per minute. In the experiments on a pulsating delivery, a device operated by a pendulum was connected to the pipe. The air was then released in gusts, with pauses in between, thus closely simulating the action of the lungs. In the cases of intermittent flow, it was sought to obtain the *maximum* water-gauge readings so as to get the "peak" values of the resistance offered by the pipe, and means were used to prevent the readings being in error through the momentum of the water in the manometer.

It is known that when air moves with a uniform speed along a large conduit, *e.g.*, a smooth-walled gallery, the resistance to passage is very nearly proportional to the square of the volume; it has also been shown that when the flow takes place through a medium such as cotton wool packed into a tube, or an extensive "waste" underground, the resistance is approximately proportional directly to the volume. In the case of a small pipe, the air-stream will neither be so free from obstruction as in the first of these cases nor so baffled as in the second. It was, therefore, to be expected that, with the hose, the index n of the formula $h = kq^n$ would prove to be somewhere between 1 and 2, and that the more the hindrance

Digitized by Google

FIG. 13.—Haldane's Equalizing Arrangement and Air Tube.

UNIV. OF MICH.

Digitized by Google

to the flow the nearer n would approach unity. Such indeed has been the conclusion of previous experimenters. We ascertained the laws of flow for the hose in question to be as follows:

(*a*) Uniform flow—tube uncoiled : $h = 0{\cdot}87\ q^{1{\cdot}62}$.

(*b*) Uniform flow—tube coiled up in 20 ins. diameter turns : $h = 1{\cdot}2\ q^{1{\cdot}37}$.

(*c*) Pulsating flow—18 breaths per minute—tube uncoiled : $H = 3{\cdot}65\ q^{1{\cdot}36}$.

(*d*) Pulsating flow—18 breaths per minute—tube coiled up in 20 ins turns : $H = 3{\cdot}8\ q^{1{\cdot}30}$.

Where : h is the resistance measured in inches of water ;
H is the maximum resistance in inches of water ;
q is the volume of air delivered per minute in cubic feet.

The first two of these results indicate that coiling up the tube introduces a considerable change in the nature of flow, the lower index of (*b*) showing that the air is meeting with hindrance through rebound and eddying. The same degree of difference is not noticeable between (*c*) and (*d*); here the jerky discharge is the dominating factor, and the interference to simple "stream-line" flow, which apparently results from the pulsating discharge, is only slightly enhanced by coiling the tube.

The bearing of these results can perhaps best be realised by considering concrete cases. If a man is standing still and drawing air direct from the 30-yard hose at the rate of 10 litres (0·35 c. ft.) per minute, the maximum resistance his lungs will have to overcome will be equivalent to 0·9 in. water when the tube is uncoiled [eqn. (*c*)], and 1·0 in. water when it is coiled [eqn. (*d*)], and in either instance the effort will be well within his power. But should he try, without an equilizing device in connection with the tube, to undertake physical work requiring a respiratory supply of 50 litres (1·77 c. ft.) per minute, his lungs would need to exercise suctions equivalent to 7·9 and 8·0 ins. water in the respective cases, and he would find it impossible to cope with such a drag for many minutes. Yet if it were feasible to introduce an equilizer to cause the air to flow in a steady stream along the tube, 50 litres per minute could be obtained at a water-gauge reading of 2·2 ins. in condition (*a*) or 2·6 ins. in condition (*b*).

The difference between a steady and a pulsating flow is still more strikingly illustrated when we come to consider the work done against resistance in drawing a given volume (say, 50 litres per minute) through the tube in each instance. To make such a comparison we shall assume that the rate of intake of air to the lungs during a breath follows the simple harmonic law; that the rate is a maximum at the middle point of the breath, and that a breath is succeeded by a pause of equal length. Such a mechanical precision of inflow—though almost exactly true in the case of an air compressor—is not, of course, followed by the lungs; but the assumption is sufficiently close for the present purpose. Taking the straight pipe without equilizer, and a delivery of 50 litres per minute, and making use of the experimental results, it can be shown that at the middle of the breath, when both speed of flow and resistance are maxima, the lungs are required to do work at the momentary rate of 230 ft.-lbs. per minute. It also appears that to maintain this intermittent delivery, the power expenditure per minute is 54 ft.-lbs. Had the flow been a steady one, the expenditure would have been only 20 ft.-lbs. Hence the pulsatory nature of the delivery increases the power spent in overcoming pipe resistance in this instance in the proportion of 2·7 to 1, while the peak load is 11·5 times the load to be borne when the flow is continuous.

The two forms of equilizers shown in the figures, while not able altogether to steady the flow, go sufficiently far in that direction to make physical exertion much more supportable while wearing the apparatus.

The original form of the arrangement, illustrated by Fig. 13, was devised in 1914 by Dr. Haldane for use in the turrets of battleships if the air became foul by gases from the guns, and for use in smoke or foul air in other parts of the ships. It is made by Messrs. Siebe, Gorman & Co., and was demonstrated at a meeting of the Institution of Mining Engineers in 1915. In this device the corrugated rubber tubing between the mouthpiece and the hose collapses in the manner of a concertina

during inspiration, while during expiration it elongates again and so fills itself with air. For use in mines, wider collapsible tubing was introduced so as to allow of work being done at long distances if necessary; even at a distance of 200 yards sufficient air can be obtained; but in ordinary practice the apparatus is only used for work at shorter distances, as in gob-fire operations or in exploring cavities and other places filled with irrespirable gas. At first saliva caused trouble in the collapsible tube, and to avoid this, the saliva trap was introduced, as shown, and afterwards the spear expiratory valve was applied in the same manner as that of Fig. 14.

In the latter appliance, designed independently in Edinburgh, the wearer carries on his back a bellows-shaped bag which is connected by a T-piece to the pipe feeding the mouthpiece. The bag is constructed of balloon fabric mounted on strips of steel, which are bent round the sharp upper angle of the bellows and thus form the frame of both the back and the front of the bag. These strips always tend to open out and thus to keep the bag distended. Their action is further assisted by a coiled spring inside the bag. When the wearer exhales, the bag, which had been partially flattened during the last inspiration, recovers itself, and in so doing draws air through the hose. On the next breath air is taken both from the bag and the pipe. The effect of the bag is thus to maintain a flow in the pipe during both strokes of the lungs, and so to smooth down the peak loads whose adverse influence has been discussed above. The mouthpiece has a Rosling inspiratory valve and a spear expiratory valve, and the saliva discharges through the latter. The spear valve is protected by a metal guard.

The Electric Head Lamp.—The use of the miner's electric head-and-belt lamp has spread enormously during the last few years in the United States and Canada, where it is said that 150,000 are in use. Certain of these lamps, *e.g.* the Edison, Hirsch, Wico, Concordia and Pioneer, were approved by the U.S. Bureau of Mines for use in gassy mines after having been tested for safety, strength and serviceableness.* The majority of the gassy mines of Pennsylvania (bituminous district), for example, are equipped with Edison lamps. It speaks well for their security that, during 1918, for the first time in the history of that field, twelve months went by without a single man being killed from an explosion of gas or dust in the bituminous district, the output of the area for the year being about 200 million tons.†

In Great Britain, it is natural that Scotland should lead in experimenting with the head lamp, owing to the prevalence in the naked-light mines of that country of the small spout-lamp which is carried on the cap. Excellent electric lamps of this kind (made at the mine) were in daily use ten years ago at the Dalmeny oil-shale mine; they were much liked, but had eventually to be withdrawn as they were not approved safety-lamps.‡ Credit must be accorded to Draeger for first applying a head lamp to rescue apparatus.

Believing that the electric head-lamp had valuable features for rescue work we obtained one from the United States, and put it into service at the Edinburgh rescue station 18 months ago. It has met with general approval and forms the subject of a recent paper by Mr. J. Cooper,§ who discussed the lamp mainly in its application to rescue operations. For such a purpose the head-lamp has the outstanding advantage over the electric hand lamp that it leaves both hands free. In operations such as that shown by Fig. 15; in travelling or carrying a stretcher in a low place; in applying artificial respiration underground; in handling a water hose or using a portable telephone, to have two hands available and yet to get a good light thrown upon the point at which the eyes are directed, is of incontestable value.

W. WALKER.
J. S. HALDANE
H. BRIGGS.

---

* *Permissible Electric Lamps for Miners*, by H. H. Clark, Washington, 1914; *Approved Electric Lamps for Miners*, H. H. Clark and L. C. Ilsley, Washington, 1917.
† MS. information from Mr. J. T. Ryan.
‡ J. B. Sneddon, *Trans. I. Min. Engs. LVII, p. 142.*
§ "*An Electric Head-Lamp*," *Trans. I. Min. Engs. LVII, p. 58.*

Digitized by Google

FIG. 14.—Briggs Equalizing Arrangement and Air Tube.

UNIV. OF MICH.

Digitized by Google

Digitized by Google

FIG. 15.—Electric Head Lamp in Use.

UNIV. OF MICH.
Digitized by Google

Digitized by Google

Digitized by Google

To face p. 41.

FIG. 16.—Briggs Compressed Oxygen Rescue Apparatus.

UNIV. OF MICH.

Digitized by Google

APPENDIX I.

THE BRIGGS COMPRESSED OXYGEN MINE RESCUE APPARATUS.

(*a*) **General Arrangement.**—In designing this apparatus it has been the aim to produce an appliance capable of satisfying the needs of the wearer while he is undertaking the hardest work, and one with which the least possible part of the man's attention is directed to the apparatus, so that he may be free, with both brain and hands, to carry out the duties he has to perform.

Fig. 16 shows the apparatus being worn, and Fig. 17 (not to scale) is its flow-diagram, the arrows indicating the direction of the air-stream.

The oxygen delivery, like that of several other apparatus, is set at the uniform rate of 2 litres per minute, and is augmented, when occasion arises, by means of a by-pass. Early in the research, attention was directed to the self-regulating oxygen-feed devices first introduced by Garforth, and developed more recently in America by Gibbs and Paul. It was recognised that a maximum economy

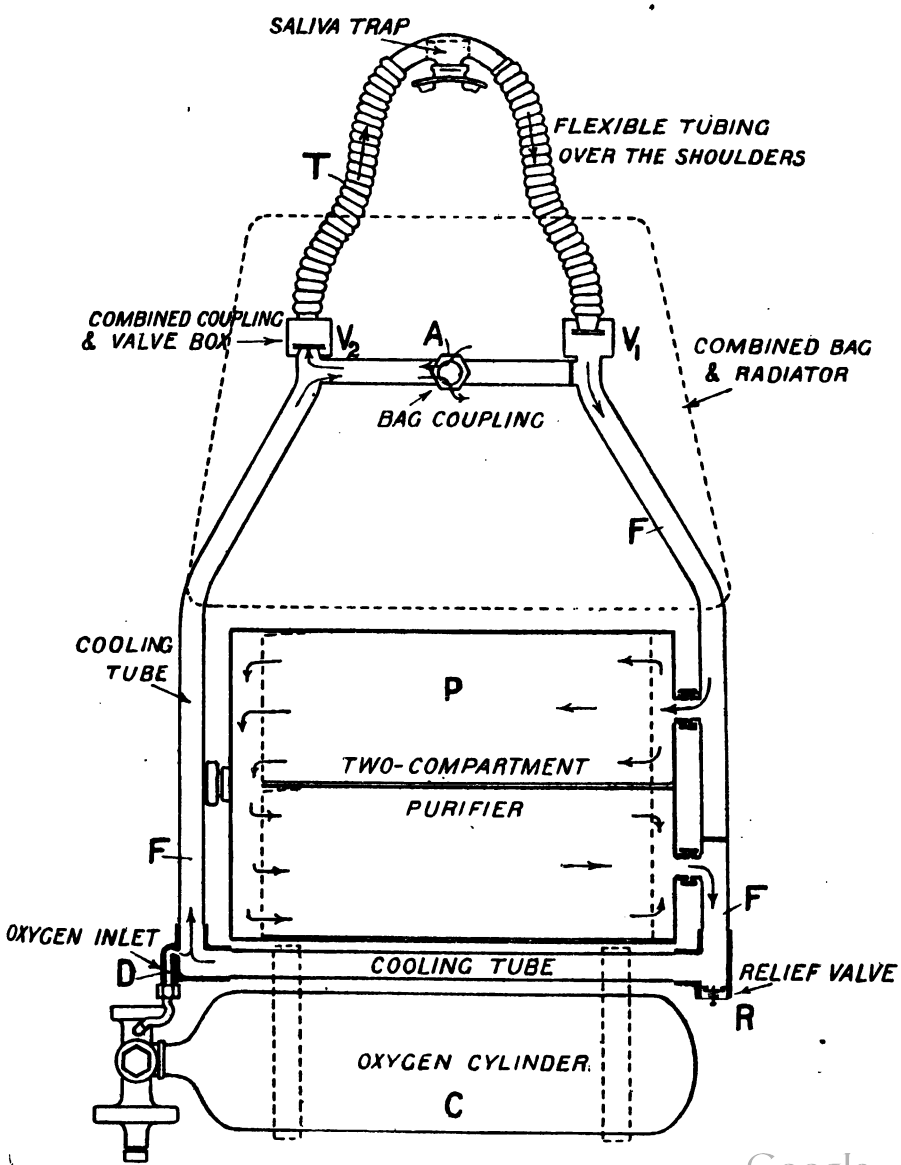


FIG. 17.—Briggs Rescue Apparatus, flow diagram.

Digitized by Google

in oxygen may be realised with such devices, and, therefore, that if a party were trapped by a fall of roof on their line of retreat, the apparatus would sustain the men (sitting still) for a long time. The self-regulating feed, however, was not adopted for the new apparatus because it is believed that, no matter how perfect mechanically that kind of feed may be, its drawbacks outweigh its advantages. In most of the work to be done by rescue apparatus 2 litres of oxygen per minute are more than sufficient; the excess, which blows off, serves the useful function of clearing away nitrogen from the circuit. In this country we have had, and in certain areas still have, the trouble of impure oxygen. Impure oxygen is especially dangerous in apparatus with automatically-controlled valves, since an accumulation of nitrogen within prevents deflation and thus prevents the oxygen feed functioning. Accidental inward leakage, as at the mouthpiece, though insufficient to give rise to distress from CO (if present), may add sensibly to this residue of nitrogen. To obviate the effects of nitrogen-accumulation in such an apparatus, it is either necessary to by-pass systematically or to arrange for a continuous slow discharge to waste from some point of the apparatus normally under positive pressure; the former method deflects too much of the attention of the wearer to his apparatus, and the second involves an additional complication, while both methods seriously detract from that economy in oxygen consumption which is the main advantage of the automatic control. Further, the automatic feeds so far designed are mechanically more complex than the constant delivery valve, and correspondingly more apt to be thrown out of adjustment.

Similar reasons decided against the adoption of the variable oxygen delivery adjusted by the wearer; the nitrogen evil is almost equally pronounced; the risk of failure through under-feeding is much enhanced; proficiency is more difficult to acquire and maintain, and far too much of the man's attention is engrossed by his apparatus.

In the present apparatus, the possibility of a team being trapped and having to eke out its oxygen as long as possible has not been overlooked, and is referred to below.

The apparatus is altogether carried on the back (in this respect resembling the Weg, Tissot, and Gibbs), thus giving freedom for the arms.

The body belt is the three-inch, webbing, infantry belt which proved itself so admirably serviceable during the war.* The slings, which are padded at the shoulders, are of narrower webbing of the same quality; their lengths are adjusted by aid of a simple device. The slings are connected to the frame by means of spring hooks.

The parts of the apparatus are supported on the back by the frame *F* (Figs. 16 and 17), which is of steel aeroplane tubing, 1 in. in diameter, weighing ½ lb. to the foot, and made by the Chesterfield Tube Co., Ltd. The frame also constitutes the greater part of the breathing circuit.

The mouthpiece, flexible tubes, *T*, and purifier, *P*, make up the remainder of that circuit.

The flexible tubes, *T*, which pass over the shoulders, are those which were provided with the first pattern of Army box respirators. They are highly flexible and durable and have no wire rings.

As Fig. 17 indicates, the air leaving the mouth passes through the valve V_1, and having circulated through the purifier, flows along the part of the circuit marked "cooling tube" and enters the bag at *A*. On inspiration, the air is drawn from the bag through the valve V_2 and into the lungs. The oxygen stream enters the circuit at *D*.

(*b*) **Oxygen Cylinder.**—The oxygen cylinder, *C*, is 13 inches long and 4½ inches in diameter. It holds 290 litres of oxygen at 120 atmospheres, and about 360 litres at 150 atmospheres pressure. For practice purposes the former pressure will ensure an ample supply for two hours, while under emergency conditions, by raising the pressure to the latter figure, the supply may be made sufficient for at least 2½ hours. The weight of the cylinder, without valve, is 7 lbs. The test-pressure is 225 atmospheres, at which pressure there must be no permanent set. The cylinder is made

Digitized by Google

* Supplied by the Mills Equipment Co., 56, Victoria Street, London, E.C.

by the Chesterfield Tube Co., Ltd., and the Research Committee is considerably indebted to Mr. H. Trevorrow, of that Company, for his interest and energy in producing this article to Dr. Briggs' specification. The Committee is also under obligation to the officers of the Technical Department of the Air Ministry, whose pioneer work on light cylinders during the war has been of much value. The metal used is a high grade carbon steel, having an ultimate tensile strength of 40 to 50 tons and a yield point of about 23 tons per sq. inch. The extremely light Air Ministry cylinders designed for aeroplanes were made of the same material, but as the metal remained under strain after manufacture, they could not be regarded as safe to use for any considerable time. The present cylinder, though heavier than the Air Board pattern, does not raise the same doubt as to persistence of strength; it is annealed at the works at 700° C. and the metal normalised—*i.e.*, relieved of strain.

Instead of being rigidly attached to the rest of the apparatus, the cylinder is secured to the lower horizontal member of the frame by two stout leather straps. Metal loops prevent it shifting laterally.

(*c*) **Cylinder Valve.**—The sunk-spindle valve of the Titan type, shown in Fig. 18, was designed with the object of getting a valve of the least weight and greatest compactness compatible with strength. After opening a valve with the key (Fig. 19),

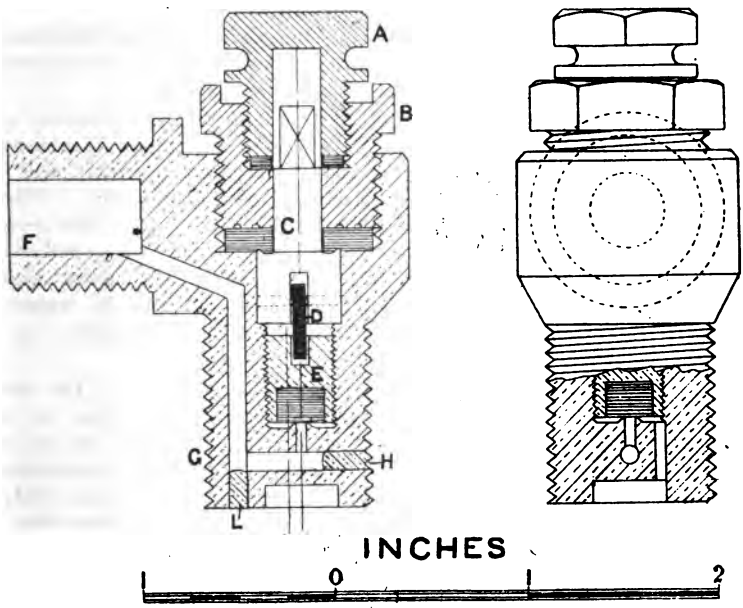


FIG. 18.—Sunk Spindle Cylinder Valve, Briggs Apparatus.

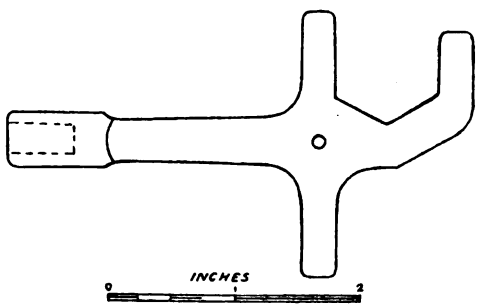


FIG. 19.—Key for Sunk-spindle Valve.

Digitized by Google

the leader of a team screws on the cap covering the sunk spindle, tightening it means of the spanner-end of the key. In this way he guards against loss of oxy along the valve spindle and makes doubly certain that there can be no tamperi with the valve while the apparatus is in use. Such a valve precludes all possibili of it being accidentally closed, and offers little or nothing to catch against projection in travelling in a narrow road.

(*d*) **Oxygen Feed Valve Gear.**—Fig. 20 is a copy on a reduced scale of th working drawings of this important part, which lies against the left-hand side o the body at the level of the waist. The gear comprises the reducing valve, by-pass, pressure-gauge and flow-meter; it is connected by a stout union, *C*, to the cylinder. The high-pressure part of the gear is of gun-metal; the rest is of aluminium. By thoroughly tinning the gun-metal centre with " kalyon," an aluminium self-fluxing solder, it has been found practicable to cast the aluminium direct upon that centre and to ensure a mechanically strong and gas-tight junction of the two metals.

The *reducing valve*, *R*, is of the single-lever variety, the lever being pressed against one side of its box by a spring, *S*, which makes sure that the vulcanite valve has no transverse movement on its seat. No rubber enters into the construction of the reducing valve; the diaphragm, *A*, is a 2-inch German silver aneroid diaphragm made by Messrs. Short & Mason, London. The metal diaphragm allows of a delicate regulation, and is very susceptible to pressure changes; it has the obvious advantages over rubber that it does not " perish," that it is stronger, and that its flexibility does not depend on temperature.

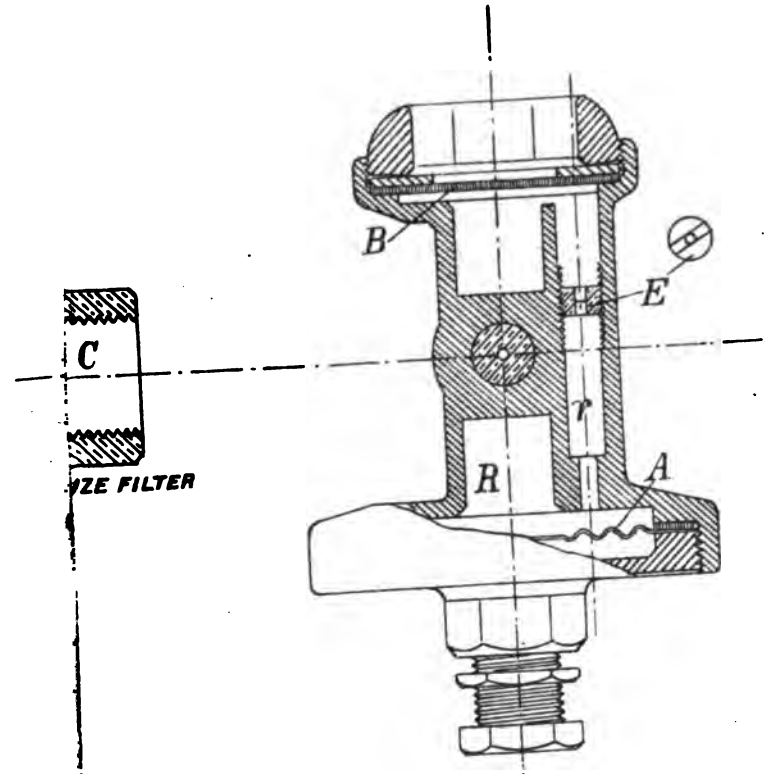
From the reducing valve box the oxygen flows through the resistance, *r* (*see* below), into the by-pass box, and thence through a 4 in. piece of stout rubber pressure tubing into the breathing circuit of the apparatus.

The *by-pass*, *B*, is worked by the pressure of the wearer's thumb, and shuts under the action of a strong spring immediately the thumb is removed. The advantage of having a by-pass which can be operated instantly and which is self-closing, will be evident to all who have used rescue apparatus. The opening at *B* is covered by a disc of strong leather or balloon fabric. The lever is only permitted to have a very small movement, to prevent the valve suffering under too hard a blow when the thumb is suddenly taken away. The guard above *B* has been added at Mr. Walker's suggestion to reduce to negligible proportions the risk of the push-button being accidentally held down by contact, *e.g.*, with a corner of rock.

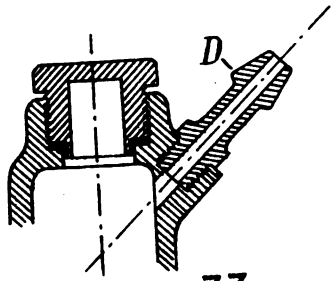
The *gauge*, *G*, has two reading points and a double scale. The front scale registers the cylinder pressure, and the back one the rate of flow of oxygen in litres per minute. The wearer can thus see at a single glance the extent of his oxygen reserve, and whether the proper discharge is being maintained. The reading window is arranged around the edge of the gauge cover, and, as glass is out of place in a rescue apparatus, it is made of non-inflammable celluloid. Applying a suggestion of Mr. W. Harris, of Llanharran, the so-called " radium " composition has been used to enable rough readings to be taken without having to shine a light on the gauge. Luminous spots are placed on the ends of each pointer, and the zero and 120-atmos. divisions of the pressure gauge and the 2-litre division of the flow-metre are similarly marked by luminous spots of distinctive shape. Both gauges are of the Bourdon type and of ordinary commercial construction. They are arranged back-to-back in the same casing. No iron or steel is used for pointers or for any other part, so that the gauges, along with the rest of the apparatus, can be tested for leakage under water without fear of rusting.

As with the Weg and Tissot apparatus, the gauge, while being rigidly and strongly connected to the cylinder, is within view of the wearer. It does not, however, project far enough to the front to be in the way when crawling; indeed, the manner of suspending the cylinder ensures that, while on all-fours, the oxygen feed gear and gauge automatically swing up and so give freedom for the arms. This mode of attaching the gauge removes the necessity of a flexible connection between it and the cylinder. A high-pressure, flexible connecting tube has three objections; first, it is vulnerable and mechanically a weak point;

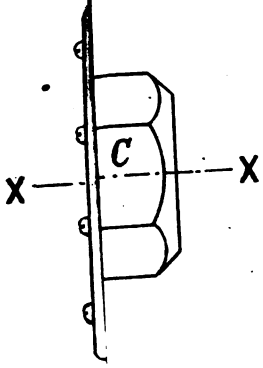
Google

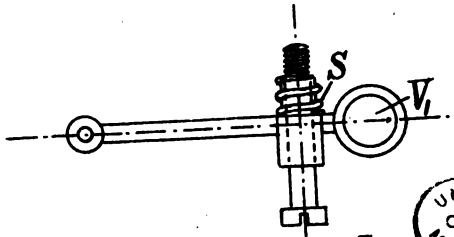


PART SECTION ON YY



SECTION ON ZZ





PLAN OF LEVER L_1

UNIV. OF MICH.

10291. 35327

Malby & Sons, Lith.

Digitized by Google

Digitized by Google

secondly, it is apt to get in the wearer's way; and thirdly, it entails the gauge being placed in a pocket, making it necessary to free one hand to extract the gauge to read it.

From the manner of connection (Fig. 20), it will be seen that the *flow-meter* is merely a gauge registering the pressure in the reducing valve box, *R*. As has been already stated, the oxygen has to pass the resistance, *r*, in order to escape from the reducing valve box. This resistance takes the place of the fine orifice placed on the out-flow side of other reducing valves; it consists of a packing of cotton-wool. The tightness of packing can be adjusted by a screw, *E*. In practice it will be found that, once set, the need for readjustment of the resistance occurs very infrequently. In setting the resistance, the regulating screw of the reducing valve is given a mid-position; the oxygen discharge nozzle is connected to a reliable litre-meter (*First Report*, pp. 31, 32, 33); the oxygen is turned on, and the screw, *E*, adjusted until the flow-gauge of the apparatus reads the same as the litre-meter. A discharge of about 2 litres per minute should preferably be selected for the purpose of this adjustment. The reason for adopting a resistance of the type described instead of the small orifice is two-fold; in the first place, as the number of paths of flow for the oxygen through the wool is extremely large, the chance of the channel being blocked by rust particles which have managed to evade the filter is almost infinitesimal; and, in the second place, with a resistance of this type, the rate of flow is almost directly as the pressure causing it, instead of being proportional to the root of the pressure as it is in the case of an orifice. In other words, we nearly attain, by these means, to a parallel of Ohm's law, and in so doing, the flow-gauge scale-divisions become almost of equal width in place of being awkwardly crowded together at one end of the scale and few and far between at the other.

(*e*) **The Purifier.**—The purifier, or regenerator, is of a form which lends itself to being re-filled at the rescue station. It consists of a strong, rectangular, tinned-metal case divided into two compartments by a horizontal partition. The canister is so made that its strength and security depend as little as possible on solder, since plain soldered joints continually in contact with caustic soda soon deteriorate. In Fig. 17 the left-hand end of the can forms the lid. The lid has a flange, 1 in. deep, which fits over the body of the can. Many methods were tried of attaching the lid to the body, and were discarded, one after another, because of their complexity or because they gave insufficient security against leakage. That finally adopted was to run a thin strip of tin round the joint and solder it to both lid and body. So sealed, the canister can be quickly opened, as a bully-beef tin is opened, by tearing off the strip, and neither lid nor case is damaged by the operation. One quickly becomes expert in making such a seal with the soldering iron, and the small additional trouble involved is repaid by the safety and strength of the joint. The solder, being external, is not in contact with the alkali.

Into each compartment of the canister there slides a carrier consisting of a trough-shaped piece of thin tin having upright ends of stout gauze. The top of the carrier is open. After the two carriers have been filled in the manner described below they are pushed into place, the lid is sealed on, and the cartridge is ready for use.

The caustic soda absorbent is supported in each carrier upon twelve light trays of stamped or crimped gauze, each tray being 7¼ ins. by 4¼ ins. The weight of metal in the purifier, including the carriers and gauzes, is 4½ lbs.

Three essential conditions have to be fulfilled in regard to the support of the absorbent in the cartridge. These conditions are: (*a*) the alkali must be uniformly distributed between the trays and over each part of a tray; (*b*) each individual granule or stick must have plenty of room in which to expand, and (*c*) the granules or sticks must be so caged that when the cartridge is jolted, they are prevented from moving out of place and accumulating at one side or at one end of the box. In the course of a long series of experiments, three methods of crimping or moulding the gauze trays (together with the necessary dies and other devices to perform the crimpling) have evolved which may claim to satisfy these conditions:

(1) The first method (first tried in 1917) is only suitable for caustic sticks; granules tend to shift if the cartridge is jolted while standing on its end. The

ordinary caustic soda stick having proved unsatisfactory for the purpose, Messrs. Crosfield, Ltd., of Warrington, kindly made up a quantity of sticks $\frac{3}{16}$ in. in diameter which gave excellent results in the fluted gauzes of Fig. 21. In this

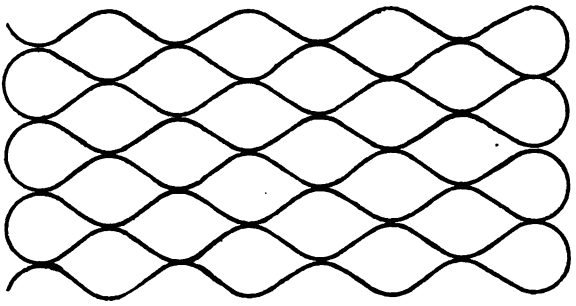


FIG. 21.—Fluted Gauze for Purifier, Briggs Apparatus.

arrangement the gauze in each compartment of the purifier is in a single length, it being crimped in a special machine to form—as the figure shows—a number of straight channels, constituting a set of air passages "in parallel." The diameter of each tubular channel is $\frac{3}{8}$ in. The crimp being placed on end, the sticks are dropped into the channels. The only objection to the method is the expense of the thin caustic sticks, whose cost will probably always lead to the second or the third method being used in practice.

(2) In the second manner of crimping, dating from 1918, the gauze trays are preferably made separate instead of being connected together in one piece. Otherwise, when the trays are in position, their cross-section is similar to Fig. 21; but if a channel be followed down, it will be found to be obstructed at three or four points along its length, either by cross-rolls in the gauze, or by the channel suddenly stepping half its diameter to one side or the other, or by aid of some equivalent expedient. In this form, the trays (which are loaded from above) are suitable for receiving granules, since the obstructions prevent the granules getting shaken to one end of the box, and thus prevent the cartridge choking soon after it is put into use. Cartridges filled in this manner have given excellent results.

(3) A useful variant on the latter arrangement was suggested by Lieutenant Rosling in 1919. The gauze trays are made to receive hexagonal-depressions of the character indicated by Fig. 22, which is a photograph of one half of the die used in pressing the trays. The caustic granules are scattered evenly in the depression. By turning the trays alternately end-for-end when putting them in the carrier, the ridges are "staggered," *i.e.*, a ridge is made to lie under a depression of the tray above, and *vice versa*. The arrangement has proved very successful; it ensures the granules staying in their proper places no matter how the cartridge may be shaken after filling.

In each of the methods described, it is found advisable to insert three strips of blotting paper in each compartment. One strip lies at the top, where it bends up against the roof of the compartment and makes a sufficiently tight closure at that place; the others are respectively placed between trays at one-third and two-thirds of the depth of the compartment. The latter strips catch and spread any drops of caustic solution falling on them.*

By the use of the forms of cartridge described above, it has been possible to get highly efficient absorption of CO_2 and very low resistance. The latter result has been secured by splitting the air, so that it traverses a compartment by a considerable number of parallel paths.

The purifier is attached to the frame by two stout brass unions, which are provided, in place of the milled nuts commonly used for rescue apparatus, with

* Attempts were made in 1917 to place the granules in crimped blotting paper in place of crimped gauze, but the idea was speedily abandoned as the crimps almost invariably caught fire spontaneously in the cartridge.

Digitized by Google

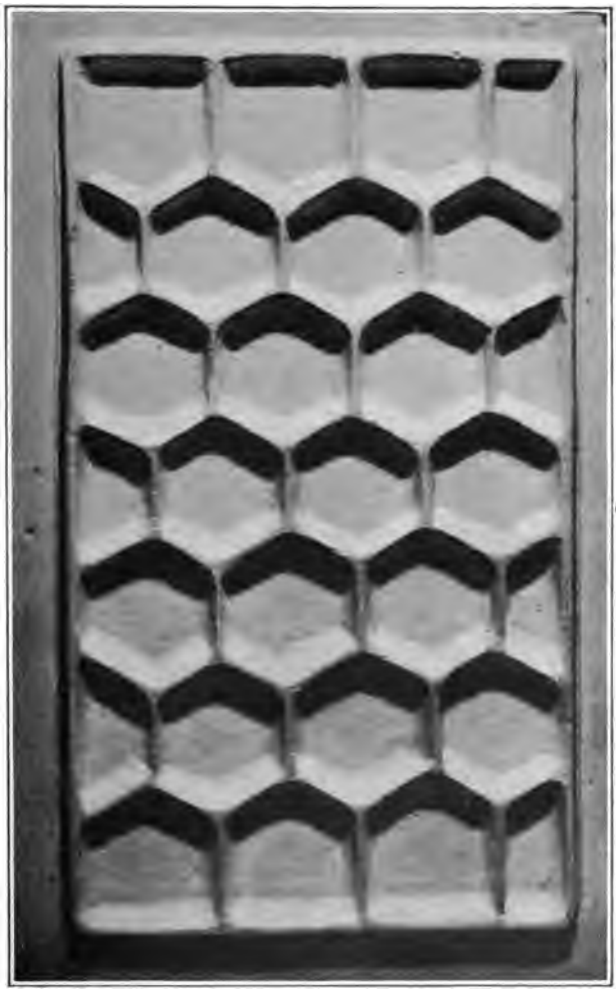


FIG. 22.—Die for stamping Gauze Trays, Briggs Apparatus.

Digitized by Google

Digitized by Google

hexagonal nuts to enable them to be securely tightened by a key. At the middle of the opposite end of the can there projects a short brass knob, which engages with a strong and simple catch and forms a third point of support for the cartridge.

As the results reveal (p. 52), a charge of 2 lbs. of caustic granules is adequate to outlast the oxygen supply during the walking test outlined on p. 22. In an actual emergency, however, and especially if the apparatus has to be used in a hot place, it is preferable to employ 4 lbs. of granules: not on account of carbon dioxide, but because the heavier charge gives cooler air. So far as carbon dioxide is concerned, it is found that a 4 lbs. charge is capable of abstracting the CO_2 discharged by a man walking at 4 miles per hour for 8¼ hours, at the end of which period the CO_2 in the inspired air rises above 2 per cent. (*see* p. 53).

(*f*) **Insulation of Purifier.**—The purifier is heat-insulated, not only at the side nearest the wearer (where there is also an air-space between it and the man's back), but on all six sides.*

The principal reason for enveloping the can as completely as possible with an insulating medium, is to prevent, or, at any rate, considerably to reduce, the dripping of the caustic inside. Dripping is due to the over-accumulation of moisture by particles of soda which, under the influence of increasing warmth, become more and more fluid and finally fall. In falling, a drip probably collides with another moist granule and induces that also to drop through the gauze. Sometimes a vertical channel, altogether clear of caustic and running the complete length of a compartment, has been observed to form in this manner. Such

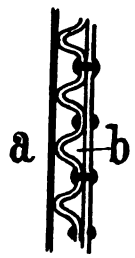


FIG. 23.—Method of Insulating Purifier ; Briggs Apparatus

a channel becomes an easy path for the air, which passes through without being properly scrubbed. Usually these channels lie against or near a cool metal surface, which has doubtless acted as a condenser of moisture during the early part of the "run"; and hence the need for covering such surfaces with a non-conductor. After trying several others, a light and strong insulator was found in the material called *leatheroid*, supplied by Messrs. Micanite and Insulator Co., Ltd., Walthamstow, London, E. The mode of application is illustrated by Fig. 23 where *a* is part of a cartridge and *b* the leatheroid cover. The latter is formed of two sheets, one corrugated and the other plain, which are fastened together by small duralumin† rivets. The corrugated side is placed in contact with the can. The envelope is in one piece.

(*g*) **The Bag.**—Like those of the Douglas respiration apparatus and the Gibbs rescue apparatus, the bag is wedge-shaped. It lies on the shoulders and has a capacity of about six litres. The bottom, the two V-shaped sides and the part which lies against the wearer's back are made of stout balloon fabric supplied by the North British Rubber Co., Ltd., Edinburgh. The remaining side, *f*, Fig. 16, is a sheet of duralumin or brass which has been blackened by chemical

* The only other breathing apparatus with a completely enclosed cartridge is the Weg, where the cartridge is carried in a leather case.

† *Duralumin*—This valuable alloy—frequently mentioned in the course of this description—is made by Messrs Vickers & Sons. Its specific gravity is approximately that of aluminium, and its strength (after proper heat treatment) nearly that of mild steel. It is tougher and springier than aluminium and forms excellent screw threads.

Digitized by Google

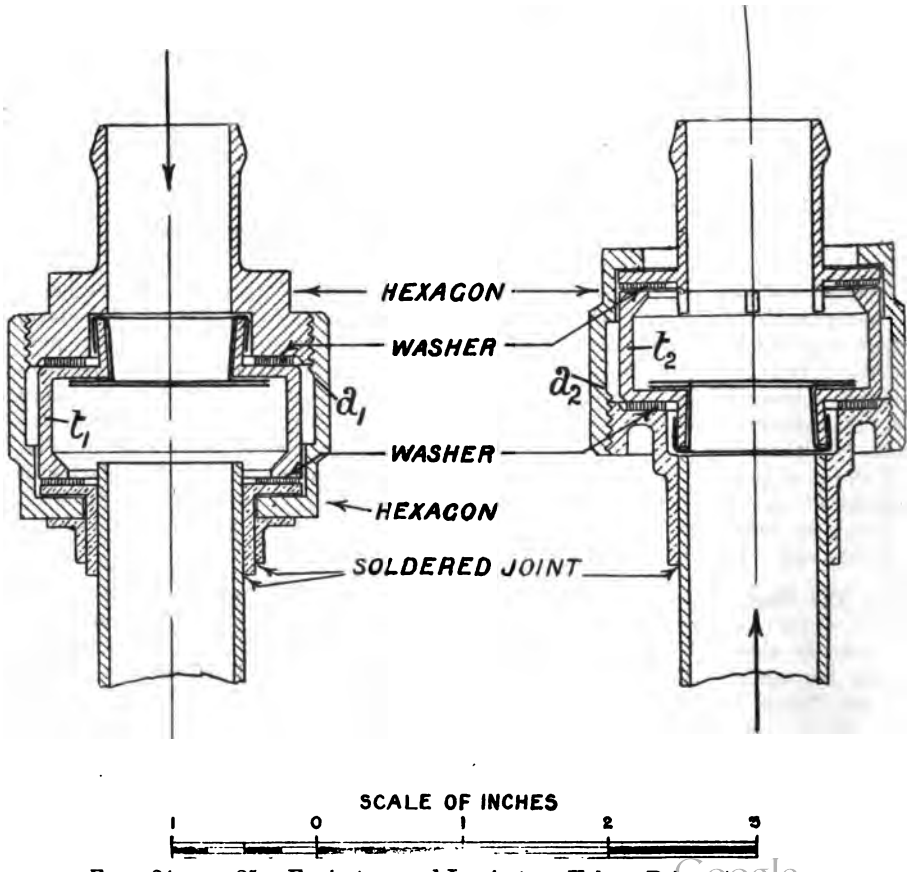
means (not by paint or lacquer) to obtain a good radiating surface. The sheet is hung from a horizontal member of the frame by strong hinges. Three advantages proceed from having this outer side of the bag of metal: (1) An additional radiating surface is obtained to assist in cooling the regenerated air; (2) The sheet affords mechanical protection and considerably reduces the chance of the bag being torn by a sharp projection; and (3) Excepting when there is a large leak in the breathing circuit, the weight of the sheet maintains positive pressure within the circuit. In the case of a large leakage the bag flattens and cannot be kept distended.

The coupling to the bag is such as to prevent the metal side suddenly closing the pipe leading from the bag when the latter is sucked almost empty.

By carrying the uprights of the frame outside in the manner shown by Fig. 16, one guards against the bag being suddenly pressed flat.

It is only when there is a serious leakage that the bag is drawn empty towards the middle of a breath. In normal use, when the bag is becoming deflated through the consumption of oxygen being in excess of the feed, the metal flap is first felt to touch down at the *end* of an inspiration; the by-pass is then pressed and the bag re-inflated during the next expiration.

(*h*) **The Inspiratory and Expiratory Valves.**—For reasons which follow from the results of the tests on rescue apparatus valves described on p. 32, the breathing valves adopted are of the Rosling pattern and of a size specially made for the present apparatus by Messrs. The Isleworth Rubber Co., Ltd. The valve boxes are attached to the tubular frame at its topmost points. By making the boxes also serve as unions connecting the frame and the flexible tubes, two joints are eliminated. The boxes, which are shown in section by Figs. 24 and 25, are of duralumin. The screws have strong, coarse threads, the unions being meant to be



FIGS. 24 AND 25.—Expiratory and Inspiratory Valves, Briggs Apparatus.

tightened hard by a key instead of screwed up by hand. The rubber valve is carried by a hollow thimble, t_1, t_2, which is of identical pattern in each case. Matters have been so arranged that if either valve be put into its box the wrong way up, the union is prevented from engaging its screw; also that if a valve be omitted, it is impossible to tighten the joint, owing to the female screw of the union being cut away at a_1, a_2. Again, it is made impossible for the half-joint belonging to the flexible inhalation tube to be coupled in mistake to the exhalation side, or *vice versa*. In other words, there is only one way of connecting up these joints, and that is the correct way.

(*j*) **The Relief Valve.**—The valve is placed at *R*, Fig. 17, where it discharges condensed moisture as well as excess air. It functions automatically (being set to blow off at about 4 ins. water column), and it can also be worked by hand if desired. Fig. 26 is a section of the valve showing how it is fitted in the brass

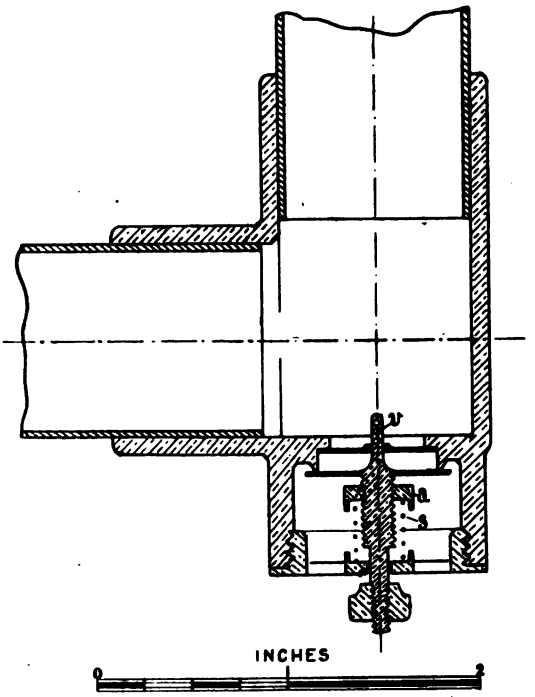


FIG. 26.—Relief Valve, Briggs Apparatus.

angle-piece. Because of its proximity to the purifier, the moisture draining into it is often alkaline, and thus neither aluminium nor aluminium alloy may be used in its construction.

(*k*) **The Frame.**—The steel tubular frame is silver-plated. As it is advisable to conserve the heat as much as possible in the expired air flowing towards the purifier, the portion of the frame between the expiration valve and the cartridge is left bright, so that its heat-emissivity may be a minimum. The remainder of the frame serves as a cooling tube; the silver plating of that part is therefore sulphided to obtain a dull black surface of high emissivity.

(*l*) **The Saliva-trap and Mouthpiece.**—(1) The metal portion of the mouthpiece is of the Tissot pattern, and is shown in Fig. 27. It being preferable to catch the saliva as near the mouth as possible, the saliva-trap and metal mouth-fitting are made in one piece. A simple conical valve, controlled by a spring, enables the trap to be emptied. To clear the saliva trap, the valve is drawn down and a sudden puff of air is ejected from the lungs, when the saliva is thrown out in

a forward direction. The valve stalk is then released. When the valve is shut, the saliva accumulating above it makes a most effectual seal. Devices were considered having the object of automatically closing the connection between the trap

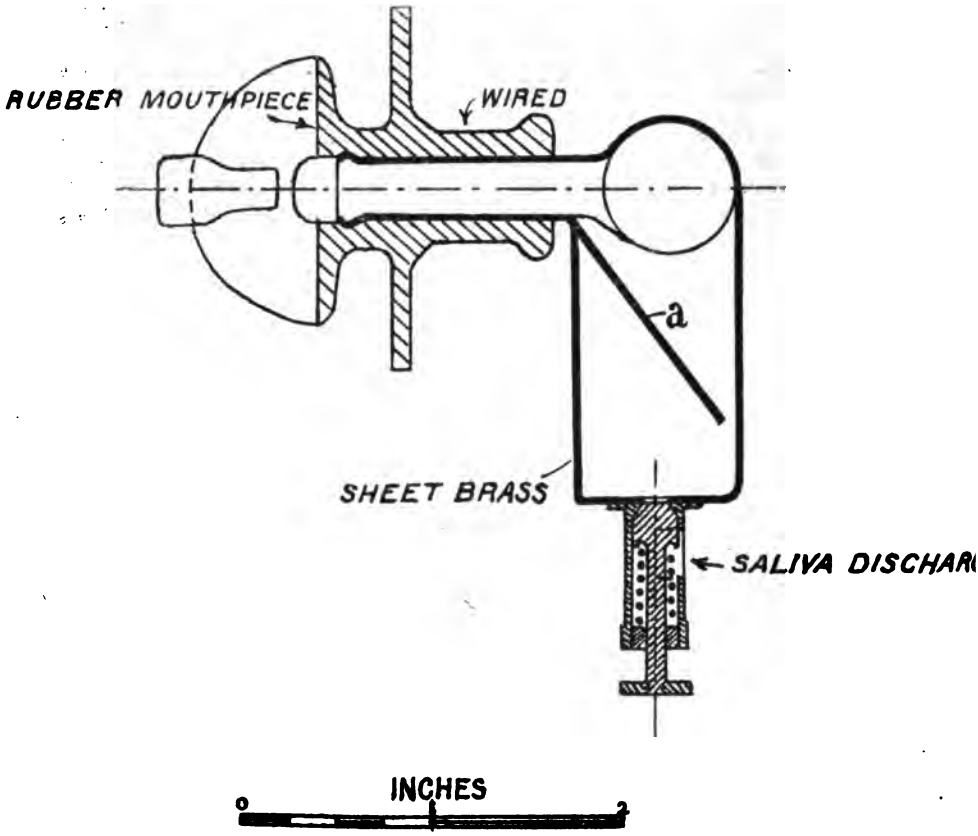


FIG. 27.—Mouthpiece and Saliva Trap, Briggs Apparatus.

and the mouth when the discharge valve was opened. Such a precaution is now deemed unnecessary. The natural thing to do in spitting is to blow out; not to draw in.

Tissot's saliva-trap has been improved by adding the inclined strip, *a*, (Fig. 27), which makes it impossible for the saliva to run back into the mouth, no matter how the head may be held.

(2) The rubber part of the mouthpiece has been designed for attachment to the head-dress described below. It can be obtained from Messrs. J. E. Baxter & Co., Leyland, Preston. For the sake of safety, the flange has been made as large as is practicable. The lugs gripped by the teeth are in all dimensions larger than usual. With other mouthpieces the lugs are so thin that the teeth have to be closed to get a firm hold. The resistance to heavy breathing through clenched teeth is very considerable, and when doing hard work while using a mouthpiece of an old design, anyone with a complete set of teeth is compelled to release the lugs and to open the jaws. To enable the grip to be maintained during heavy exertion, the lugs of the present mouthpiece are thickened. In Fig. 28 the man is wearing an ordinary mouthpiece, which was cut level with the flange to make the teeth more visible, and in Fig. 29 he is using one of the new pattern. In the first photograph the teeth are closed; in the second they are open.

Digitized by Google

FIG. 28.—Position of Teeth when using ordinary mouthpiece.

FIG. 29.—Position of Teeth when using mouthpiece of Briggs Apparatus.

UNIV. OF MICH.
Digitized by Google

Digitized by Google

To assist in making the hold on the lugs more secure they are, like the stem of a tobacco pipe, moulded with swellings at their extremities. Mr. Winborn called attention in 1918 to the desirability of such swellings; a recent Weg mouthpiece and one variety of the army mouthpiece also have lugs with thickened ends.

There are no tapes fastened to the mouthpiece; their absence facilitates disinfecting.

(*m*) **Headdress and Noseclip.**—The cap is of skeleton pattern, wide holes being left to allow of ventilation when working in a hot place. The circumstances of any case will decide as to the advisability of using a further head covering in addition to the skeleton cap.* The cap is made of sail cloth, strongly bound at its edges with wide bootmaker's braid, and at the front elastic bands are provided to enable the cap to adjust itself to the wearer's head. These bands are similar to those used by the Germans for their gas helmets during the war, each consisting of two steel springs enclosed in cotton fabric. The springs are silver plated so as to be unaffected by moisture. Unlike rubber elastic, this variety does not lose its "nature" in course of time. The cap serves to support two cheek plates (due to Lieut. Rosling) to which the nose clip and rubber mouthpiece are hooked. A cheek plate is of duralumin with a layer of felt riveted to the side which lies against the face. The bands supporting the cheek plates are specially made of non-fraying webbing by Messrs. Rawle, Jermyn Street, London, S.W., and each can be adjusted in length by a simple wedge device.

The nose clip is of the screw pattern, and was developed from a clip that has been in use at Wath Rescue Station for some years. Being secured to the cheek plates in the manner shown by Fig. 16, the clip is difficult to displace, and its security is increased by the metal bridge of the clip passing under, instead of over, the nose; there is thus nothing projecting in front of the nose to be caught or to be struck by a chance blow. In addition to its security, this clip proves most comfortable to wear, since the degree of pressure upon the nostrils can be regulated so as to be sufficient to close them without being excessive.†

(*n*) **Emergency Oxygen Feed.**—As has been stated, the captain of a team carries the key (Fig. 19) with which the oxygen cocks are turned on. In the case of a team being trapped and unable to return to its base, it is intended that the captain should, by means of the spanner end of the key, remove from the reducing valve of each apparatus the adjusting screw and spring controlling the pressure on the diaphragm. It will then be found that the valve gives an oxygen flow of about 0·4 litre per minute, which is sufficient to sustain a person sitting or lying still, especially as the by-pass is always available in case the supply needs to be supplemented. In the rare, but nevertheless possible, contingency under consideration, a team would in this way be enabled to eke out its oxygen for many hours.

(*o*) **Weight.**—The complete apparatus, charged with 3 lbs. of caustic soda granules, weighs 29 lbs.

Records of Tests with the Briggs Apparatus.—The apparatus has been subjected to a number of tests carried out by various persons. These tests uniformly involved greater respiratory exertion than is likely to be needed, in the same length of time, during actual service in the mine.

In all cases the reducing valve was set, at the beginning of a "run," to give 2 litres of oxygen per minute. The purifier was charged with granulated caustic soda of the weight stated in each instance. The temperature rise is the difference

---

* It is of interest to state that as early as 1906, an openwork cap was used with the Weg apparatus. In that instance, the crown of the cap was of string net. The object, as in the present instance, was to provide copious ventilation for the head.

† Early in 1919, the Department of Scientific and Industrial Research, at the desire of the Mine Rescue Apparatus Research Committee, issued a pamphlet on nose clips. The pamphlet illustrated a clip resembling that described above and a modified Proto skull cap to which the clip was attached. The present headdress is an advance on that of the pamphlet. About 30 of the combined headdress noseclip and mouthpiece of Fig. 16 were distributed to rescue station instructors and others towards the middle of 1919.

Digitized by Google

between the temperature of the inspired air and that of the outside atmosphere. Carbon dioxide determinations were made with the Haldane gas-analysis apparatus.

Endurance Tests.—In these the subject walked for two hours, or for the time specified, at 4 m.p.h. round a level court. The routine set forth on p. 22 was exactly followed.

(1) **Subject H.B.**—Four lbs. caustic soda.

After walking	½ hour ;	CO_2 in inspired air,	*nil* ;	temperature rise,	9° F.
,,	1 hour ;	,,	*nil* ;	,,	11° F.
,,	1½ hours ;	,,	*nil* ;	,,	23° F.
,,	2 hours ;	,,	*nil* ;	,,	25° F.

The subject then ran 400 yards at about 5½ m.p.h., after which the CO_2 percentage was again found to be *nil*. The temperature rise was 35° F. Resistance of the whole circuit (mouthpiece to mouthpiece) to a flow of 85 litres per min., measured after the run, 1·3 ins. w.g.

(2) **Subject D.D.**—An exact repeat of (1).

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	4° F.
,,	1 hour ;	CO_2,	*nil* ;	,,	10° F.
,,	1½ hours ;	CO_2,	*nil* ;	,,	14° F.
,,	2 hours ;	CO_2,	*nil* ;	,,	17° F.

After running an additional 400 yards, CO_2, 0·24 per cent.; temp. rise, 24° F.

(3) **Subject C.R.**—An exact repeat of (1), except that the running at the end was omitted.

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	12° F.
,,	1 hour ;	CO_2,	*nil* ;	,,	13° F.
,,	1½ hours ;	CO_2,	*nil* ;	,,	21° F.
,,	2 hours ;	CO_2,	*nil* ;	,,	28° F.

(4) **Subject D.D.**—The same test repeated, but with a charge of 3 lbs. granulated caustic soda in the purifier.

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	9° F.
,,	1 hour ;	CO_2,	*nil* ;	,,	19° F.
,,	1½ hours ;	CO_2,	0·35% ;	,,	29° F.
,,	2 hours ;	CO_2,	0·78% ;	,,	33° F.

After running an additional 400 yards, at about 6½ m.p.h., CO_2, 0·78 per cent., temp. rise, 39° F. Subject preferred the heavier charge of caustic, because the air was then cooler. Resistance of the whole circuit to a flow of 85 litres per min., measured after the run, 1·4 ins. w.g.

(5) **Subject R.M.C.**—The same test repeated; 3 lbs. caustic soda.

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	5° F.
,,	1 hour ;	CO_2,	*nil* ;	,,	28° F.
,,	1½ hours	CO_2,	0·24% ;	,,	36° F.
,,	2 hours ;	CO_2,	0·18% ;	,,	29° F.

(6) **Subject J.C.**—The same test repeated, but with only the upper compartment of the purifier charged with 2 lbs. caustic granules.

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	6° F.
,,	1 hour ;	CO_2,	0·18% ;	,,	18° F.
,,	1½ hours ;	CO_2,	0·41% ;	,,	23° F.
,,	2 hours ;	CO_2,	0·47% ;	,,	25° F.
,,	2¼ hours ;	CO_2,	1·57% ;	,,	24° F.

(7) **Subject R.M.C.**—Repeat of (6); 2 lbs. caustic soda.

After walking	½ hour ;	CO_2,	*nil* ;	temperature rise,	13° F.
,,	1 hour ;	CO_2,	0·18% ;	,,	31° F.
,,	1½ hours ;	CO_2,	0·82% ;	,,	34° F.
,,	2 hours ;	CO_2,	1·32% ;	,,	32° F.

Digitized by Google

(8) **Climbing Test. Subject H.B.**—The test consisted in climbing Arthur's Seat, Edinburgh, and was to ascertain the behaviour of the apparatus under sustained heavy exertion. The climb (involving a vertical rise of 640 feet) was performed without difficulty or incident in 21 minutes, and the descent to the starting point in 9 minutes. In ascending, the subject did over 100,000 ft. lbs. of external work; his oxygen consumption on the upward journey averaged about 2·8 litres per minute. A full charge (4 lbs.) of caustic soda was used. Samples of air for analysis were withdrawn from the inspiration tube at the summit and after descent. Owing to the breeze the cooling of the air was highly efficient.

On reaching summit; CO_2 0·43%; temperature rise, 4° F.
" bottom; CO_2, 0·12%; " 4° F.

Exhaustion Tests on Purifier.—To ascertain the full capability of a purifier charged with 4 lbs. caustic granules, and to what extent it outlasts the oxygen supply, the wearer walked on the level at 4 m.p.h., the temperature readings and air samples being taken in the manner stipulated on p. 22. The oxygen cylinder was recharged when exhausted and the test continued. The times stated below do not include those occupied in recharging the cylinder. The subjects worked in shifts of 1½ hours, the apparatus being handed over to another man after such a shift.

(9) **Subjects D.P. and C.R.**

After walking ½ hour	CO_2, *nil*	temperature rise,	4° F.
" 1 hour	CO_2, *nil*	"	14° F.
" 1½ hours	CO_2, *nil*	"	26° F.
" 2 hours	CO_2, 0·12%	"	14° F.
" 2½ hours	CO_2, 0·24%	"	26° F.
" 3 hours	CO_2, 1·00%	"	32° F.
After walking 3 hours 6 mins. and then running at 8 m.p.h. for 2 mins.	CO_2, 2·24%.		

(10) **Subjects H.B., D.P. and D.D.**

After walking ½ hour	CO_2 *nil*	temperature rise,	3° F.
" 1 hour	CO_2, *nil*	"	9° F.
" 1½ hours	CO_2, 0·12%	"	16° F.
" 2 hours	CO_2, 0·25%	"	13° F.
" 2½ hours	CO_2, 0·59%	"	23° F.
" 3 hours	CO_2, 1·32%	"	23° F.
" 3 hrs. 21 mins.	CO_2, 2·47%	"	17° F.

Sudden Exertion Tests.—In these tests the wearer of the apparatus walked for 26 minutes at the rate of 3 m.p.h.; he then ran 300 yards at 6–7 m.p.h., after which he walked for 2 minutes at 3 m.p.h., when the samples and readings were taken. This routine was repeated four times, occupying two hours in all.

(11) **Subject B.B.**—Four lbs. caustic soda.

Walking 26 mins.; running 300 yds.; walking 2 mins.;	CO_2, *nil*;	temperature rise,	9° F
" " " second spell;	CO_2, *nil*;	"	19° F.
" " " third spell;	CO_2, 0·12%;	"	27° F.
" " " fourth spell;	CO_2, 0·25%;	"	33° F.

Resistance of whole circuit to flow of 85 litres per minute, measured after the test, 1·7 ins. w.g.

(12) **Subject J.C.**—Four lbs. caustic soda.

Walking 26 mins.; running 300 yds.; walking 2 mins.;	CO_2, *nil*;	temperature rise	6° F.
" " " second spell;	CO_2, *nil*;	"	10° F.
" " " third spell;	CO_2, *nil*;	"	18° F.
" " " fourth spell;	CO_2, *nil*;	"	22° F.

Resistance of whole circuit to flow of 85 litres per minute, measured after the test, 1·6 ins. w.g.

H. B.

Digitized by Google

APPENDIX II.

FITNESS TESTING WITH THE ERGOMETER.

The apparatus named is the bare minimum needed, and the description here given is of the method reduced to its simplest form.

Apparatus: (1) **Martin's Ergometer.***—The machine is to be seen in Fig. 30, which shows the arrangements at the Physical Test Station. It consists of a cycle frame and seat, a heavy fly-wheel having been substituted for the back-wheel of the bicycle. Round the fly-wheel passes a belt, the ends of which are connected by adjustable cords to spring balances. The belt is of linen or sail cloth, wires being run through the hems at each side of the strip of cloth to prevent the belt slipping off the wheel. Care should be taken to dry the belt thoroughly before using, or the balance readings will be found to fluctuate. A pendulum, hung to be constantly in view of the subject, gives the rate of speed of pedalling. With the size of fly-wheel and gear-ratio of the cycle usually supplied for the ergometer, the pendulum can conveniently be adjusted to make 56 swings a minute, since at that rate of pedalling the work done in foot-pounds per minute is obtained by multiplying the difference of the balance readings (in pounds) by 1,000. Whatever may be the rate of pedalling selected, the product of the difference of the balance readings and the distance (in feet) moved per minute by a point on the circumference of the fly-wheel measures the work done in foot-pounds per minute. Various rates of work can be set by tightening or slackening the cords attached to the belt.

(2) **Gas-analysis Apparatus.**—Carbon dioxide analysis being all that is required in the simplified method, a Briggs apparatus (p. 51, *First Report*) proves serviceable and speedy, a burette graduated along its entire length being used, and caustic potash solution, instead of alkaline pyrogallol, being placed in the absorption pipette. One of the assistants is seen using this apparatus at *B*, Fig. 16.

(3) **Douglas Bag.**—The 60-litre size, fitted with a three-way aluminium stop-cock is required. It is a bellows shaped bag of convenient form to collect expired air. In Fig. 30 it is on the table, and a sample from it is being forced by pressure into the gas-analysis apparatus. When that operation is over, the bag, squeezed empty, is connected to the rubber tube, *A*, through which the subject is exhaling. More usually it lies on the table at the side of the ergometer, thus keeping the connecting tubing short in length.

(4) **Mouthpiece, Noseclip and Valves.**—Any rescue-apparatus mouthpiece and noseclip serves the purpose. The best valves are the Rosling type (*see* p. 31). They are obtainable from the Isleworth Rubber Co. The valve-boxes and Rosling valves of the Briggs rescue apparatus (p. 48) will be found suitable.

(5) **Connecting Tubing.**—To avoid unnecessary resistance, the connections should be of one inch bore.

(6) **Oxygen Supply Cylinders, Oxygen Collecting Bag and Bubbler.**—The 100-ft. cylinders are the most serviceable. The cylinder in use is fitted with a reducing valve. From the reducing valve the oxygen is made to bubble through water and then to enter a distensible collecting bag. A cheap and useful form of bag is that used for holding coal gas on tradesmen's small motor vans. The injector device described in the footnote, p. 12, may be placed immediately after the reducing valve to economise in oxygen. When the subject is breathing oxygen, the reservoir bag should be kept about three-parts full. Over-distension of this bag may create sufficient pressure to force oxygen through both valves, and is, therefore, to be avoided. In Fig. 30 the reservoir bag is at *C*, under the table. The meter to be seen in that photograph enabled the volume breathed per minute to be recorded, and the movements of the pointer of the meter allowed the rate of breathing to be determined. For the sake of simplicity, however, the meter is here omitted.

---

* Journ. Physiol. 1914, XLVIII. Proc. Physiol. Soc., p. xv

Digitized by Google

FIG. 30.—Testing with the Ergometer, Physical Test Station, Edinburgh.

To face p. 54.

Digitized by Google
UNIV. OF WISCH.

Digitized by Google

Method of Conducting Experiments.—The subject, seated on the saddle, is fitted with the mouthpiece and noseclip. He breathes air from the room. While he is at rest the 3-way tap is turned, at the end of an expiration, to the " on " position, that is, so that the breath passes into the Douglas bag. It is kept in that position for a period of about two minutes, when the tap is turned off at the end of an expiration. The Douglas bag, now partially inflated, is put on the table; kneaded to mix its contents; connected to the supply tube of the Briggs analysis apparatus, and, with the tap in the " on " position, squeezed to force a few litres of the products of expiration through the burette. The sample so obtained in the burette is then analysed for CO_2. This procedure avoids the need for sample tubes or sample bottles.

The Douglas bag is then emptied by pressing it flat, and is again attached to the expiration tube connecting to the mouthpiece. The tap being in the " off " position, the subject is required to pedal (at the rate of the pendulum) at no load, *i.e.*, with the belt off, for a timed period of 2 minutes. At the end of an expiration the tap is turned " on " and expired air allowed to accumulate in the Douglas bag for another 2 minutes of pedalling. The tap is again turned off after an expiration and the CO_2 percentage determined.

The belt is put in place; its cords are adjusted to give a difference of 3 lbs. between the balance readings, and the same sequence of operations is followed. Similar observations are made at balance-differences of 6, 9 and 12 lbs. Longer pauses should be allowed between the higher loads to allow the man to recover fairly completely from the effect of one spell of exercise before attempting another. Effort should be made in all cases to sustain the load for two timed minutes before allowing expired air to enter the Douglas bag. This preliminary interval has perforce to be cut down on the highest loads (12 lbs. or 14 lbs.) as no one in our experience has been able to bear them two minutes or more; but in no case should the preliminary period be reduced below one minute. The interval spent in inflating the Douglas bag, however, can be safely reduced to 30 seconds or so when the work is severe, providing that the tap is opened and closed at the same phase of breathing—preferably at the end of expiration. A record wherein the correct rate of pedalling is not maintained must be discarded.

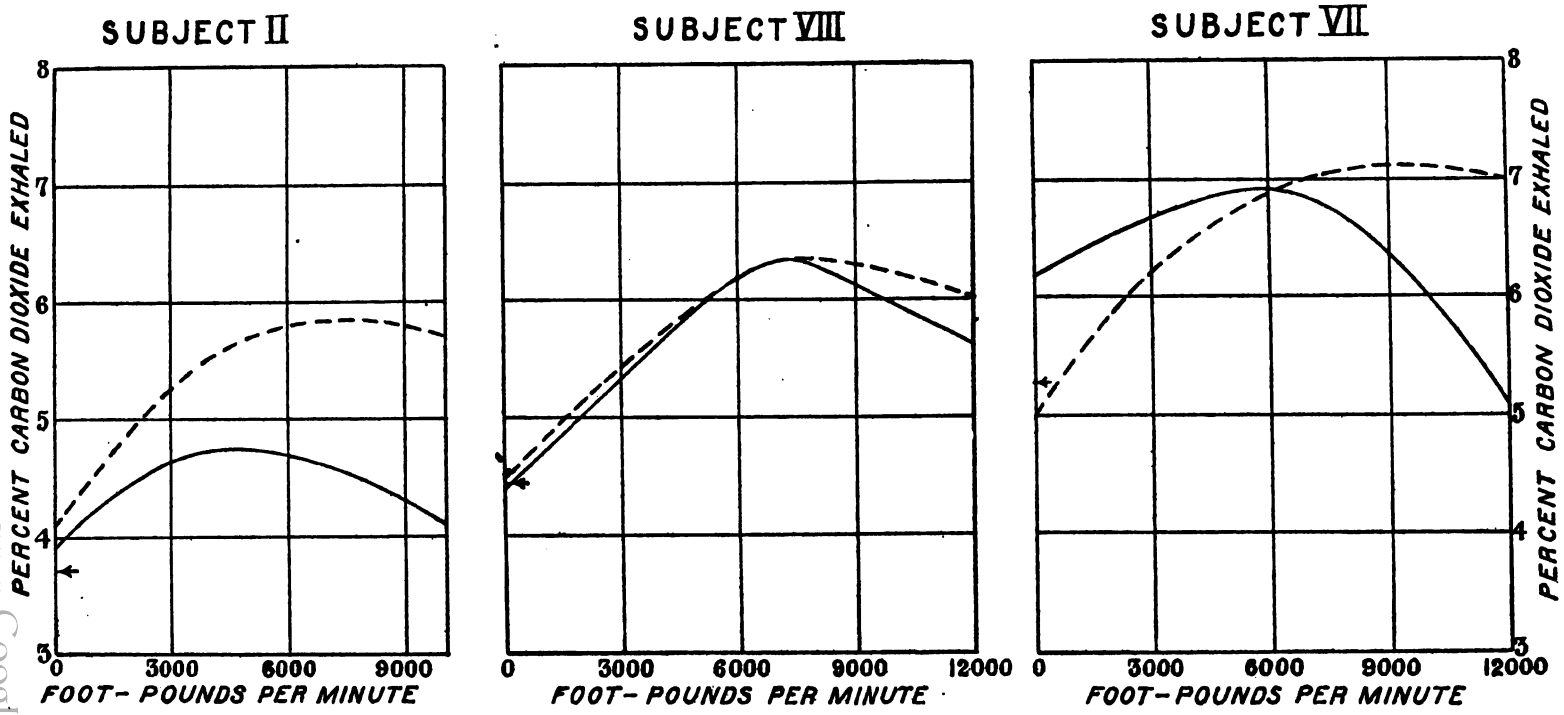
After this series of results has been obtained with the subject breathing air, an exactly similar series (excepting that the resting experiment may be omitted) is taken with the man breathing oxygen from the reservoir bag. Before the latter measurements are taken, however, it is advisable that he should breathe oxygen for about 10 minutes to swill out most of the nitrogen in solution in the blood and tissues.

Recording and Interpreting Results.—A test carried out in the above manner furnishes data such as those of Table I, p. 12.

The data are best set forth in the form of graphs in which the loads are plotted as abscissae and the CO_2 percentages as ordinates. Figs. 31 to 37 reproduce such graphs; the curves drawn in full lines show the relation between load and expired CO_2 percentage when breathing normal air; those in dotted lines that relation when breathing oxygen. The CO_2 proportion when the subject is resting and breathing air is in each case indicated by an arrow-head. Figs. 31 and 32 are constructed from the data of Table I.

It will be observed that the curves are in all instances dome-shaped; the CO_2 percentage rises from the resting value to a maximum and then falls again. The fall indicates oxygen-want. The immediate effect of the oxygen supply being less than the demand is to increase the lung ventilation. Enhanced breathing, which with the high loads becomes hard panting, dilutes, through sheer excess of air, the CO_2 discharged, and the CO_2 percentage accordingly drops. The load yielding the maximal CO_2 percentage (the " crest load ") may be taken as demarcating between normal load and overload. In other words, the man can sustain loads up to the crest value for some considerable time, as his oxygen input is adequate to deal with such rates of work; but he can only bear loads above the crest value for a brief period.

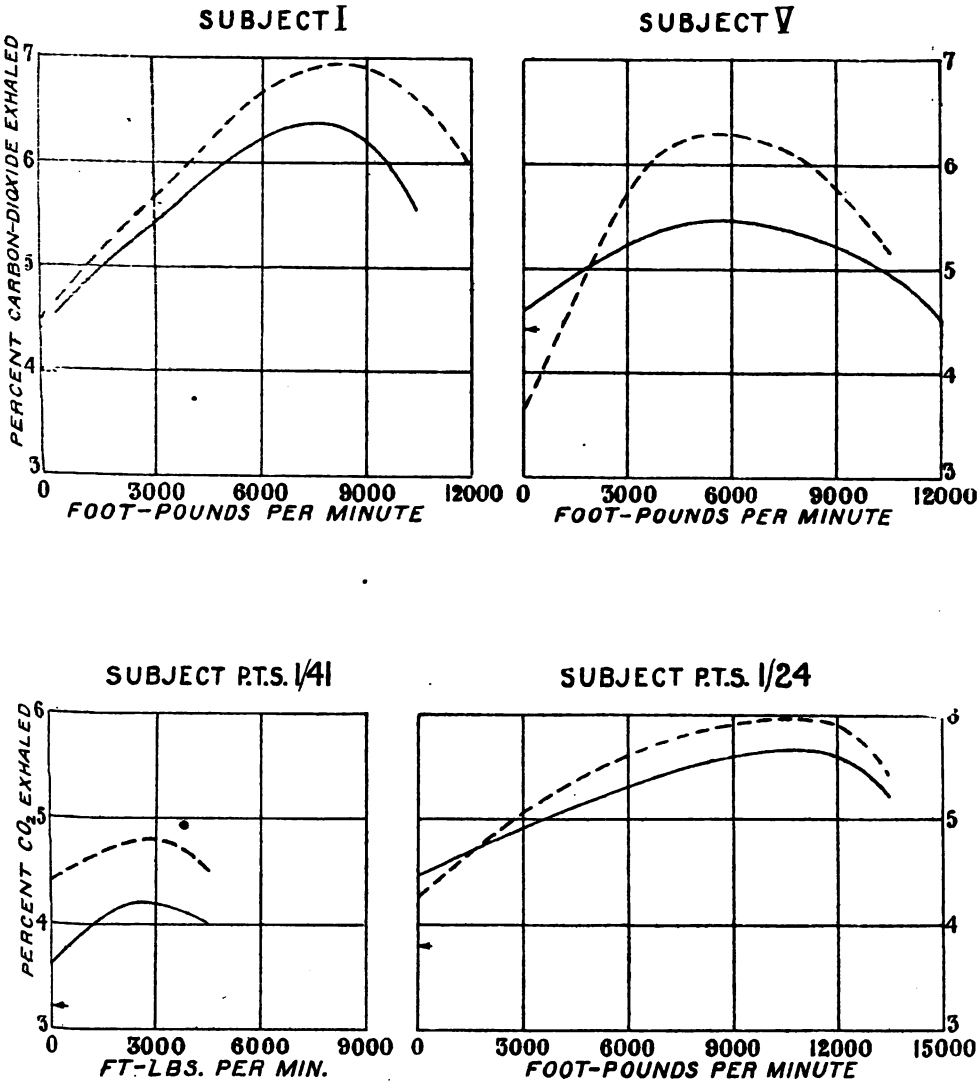
Digitized by Google



FIGS. 31-33.—Ergometer Testing ; Graph records.

Digitized by Google

A useful measure of the stamina of a man (*i.e.*, his power of supporting sustained physical effort) is furnished by the position of the crest load; the higher it is the better. The crest load, when breathing enriched air, of a strong man in the prime of life and inured to labour, is generally over 9,000 ft. lbs. per min. It is doubtful policy to keep in a rescue brigade (except, perhaps, as leader) anyone whose crest load on oxygen is 6,000 ft. lbs. or less.



FIGS. 34–37.—Ergometer Testing: Graph records.

The difference made in these records by condition or fitness becomes clear when the graphs of Fig. 31 are contrasted with those of Fig. 32. In the former case the subject is a relatively unfit, sedentary person, while in the latter he is an Army instructor in physical drill, who was selected for experiment by the Scottish Command as representing physically the best the Army can produce. The curves of Subject II diverge, while those of Subject VIII are practically coincident. A simple and useful method of expressing the fitness of a subject is to divide the crest-ordinate of the "air" curve by that of the "oxygen" curve, the level of

Digitized by Google

the arrow-head (CO_2 value, resting) being used as datum for each measurement. By that system the fitness of Subject II is 46 per cent., while that of Subject VIII is 100 per cent. The fitness of the healthy working miner usually exceeds 75 per cent.; evidently it is advisable that a permanent brigade member should also be at least as fit.

NOTES ON THE SUBJECTS OF THE ACCOMPANYING GRAPHS.

Subject II.—Sedentary person: weight, 136 lbs.; fitness, 46 per cent. Work much easier on oxygen than on air. The subject would probably respond favourably to physical drill, though his power of dealing with sustained exertion would never be large.

Subject VIII.—Regular soldier: weight, 168 lbs.; instructor in physical drill; athletic type; fitness 100 per cent. Judging by his general behaviour while doing work (quite apart from the results obtained), he is the fittest man we have tested. Breathing oxygen is not the least benefit until the crest load is exceeded; then it gives a gradually increasing assistance.

Subject VII.—Manager of a mine working steep seams: trained rescue man; weight 169 lbs.; fitness 88 per cent. His daily work involves a lot of clambering in steep, low roads. Slow, deep breather. The high level of the CO_2 percentages and the correspondingly small volumes taken into the lungs per minute are noteworthy features. Thoroughly suitable as member of rescue brigade.

Subject I.—Miner (repairer) working in steep seams: weight, 154 lbs; trained rescue man; fitness, 83 per cent.; high stamina; thoroughly suitable as member of rescue brigade.

Subject V.—Member of resident brigade for 2 years; previously a miner; weight, 142 lbs. This man was selected to see if the fitness of these brigade members deteriorates owing to their light duties, and the results, when compared with those of men constantly working underground, indicate a considerable falling off in both fitness and stamina. Fitness, 56 per cent.; unusually rapid breathing at the heavier loads. The fact that the subject breathed quicker on oxygen than on air for low loads may explain the crossing of the curves. The subject recently succumbed while wearing a defective rescue apparatus.

Subject P.T.S. 1/41.—Selected from the Physical Test Station records; infantryman of one of the older groups called up in 1918; age, 44; weight, 133 lbs.; foremerly a painter. Introduced here to illustrate the deterioration that sets in with age. The report of the testing officer was:—"*Stamina:* Very poor. *Condition:* Poor. *Observations:* Not worth training; no use as infantryman. *Recommendations:* Suggest that he be set to his own trade."

Subject P.T.S. 1/24.—Selected from the Test Station records as a contrast to the last instance. Well-developed cadet of 18 years; weight, 175 lbs.; all-round athlete. The testing officer reported:—"*Stamina:* Excellent. *Condition:* Excellent. *Observations:* First-rate material; fit for anything. Probable increase of fitness from P.D., 10 per cent."

H. B.

Digitized by Google

INDEX.

PAGE.

Altofts rescue station 34, 35
Alveolar air 7
American bureau of mines ... 5
Approval of rescue apparatus ... 5, 20
Army respirator, warning against 36
Ashington colliery fire 37

Box respirator, warning against 36
Breathing—against resistance ... 9
—air rich in oxygen, effects of 8, 12
—effects of CO_2 excess on 9
—effects of oxygen—want on 9
—periodic 9
—purpose of 7
Briggs, Henry ... 3, 5, 6, 11, 12, 13, 18, 19
Briggs' equalizing arrangement 40
gas analysis apparatus ... 54
mine rescue apparatus ... 5, 41
Brown, G. L. 20, 34
Burdiehouse mine—tests at ... 13
By-pass 21, 44

Calcium chloride cooler 24
Carbon dioxide excess 9
Carpenter, T. M. 31
Choking of reducing valves ... 28
Clifford, W. 25
Climbing tests 13, 52
Compressed air—working in ... 13
Cooler—calcium chloride ... 24
—sodium sulphate ... 24
Cooper, J. 20, 28, 40
Coslettising process 26
Crimping gauzes 46
Crumlin rescue station 23, 34
Currie, R. J. 23
Cylinder valve—sunk spindle ... 43

Deaths due to rescue apparatus ... 17
Discharge of blood—nitrogen ... 8
Doncaster tests 23
Douglas bag 47, 54
Draeger mine rescue apparatus ... 17
Drying of oxygen 27
Duralumin 47

Edinburgh rescue station 14, 27, 40
Eeds helmet—warning against ... 36
Effects of air rich in oxygen ... 8, 12
breathing oxygen—fallacious views on ... 8
Electric head lamp 40
ndurance test 22, 52
Ergometer 54
testing—graph records 56
Equalizing arrangement—Briggs' 40
—Haldane's 39
Exertion—oxygen consumption during 14
Exertion—physical 10
Expiration valves—test of ... 22

PAGE.

Face masks 23, 24
Fatigue, respiratory 10, 11
First Report, Mine Rescue Apparatus Research Committee, 5, 7, 8, 18, 19, 25, 35, 45, 54
Fitness testing 13, 54
recording results... 55
Flow gauge for Proto apparatus... 36
Briggs' apparatus 45

Garforth, Sir William 41
Gas—analysis apparatus—Briggs' 54
—Haldane's 52
Gibbs' mine rescue apparatus ... 17, 42
Gilchrist, Miss E. 6, 24
Graph-records—ergometer testing 56

Haldane, J. S. 3, 7, 13, 30, 39
Haldane's equalizing arrangement 39
gas analysis apparatus 52
Harris, W. 44
Head-lamp—electric 40
Henderson, Yandell 7
Homestake mine fire 37
Hood, J. A. 6
Hopwood, W. 34

Inspiration valves—test of ... 22
Inspired air—cooling of 23
—temperature of ... 22, 23
Insulation of purifier 47

Japanning cylinders 26

Lactic acid—formation of ... 11
Lambert, Major 34
Liquid air rescue apparatus ... 5, 22
Logan, Lt.-Col. D. D. 18, 36
Lorrain-Smith, Prof J. 9

Mackay, M. 6
McConnell, F. J. 6
Meco rescue apparatus ... 19, 25, 28
Mica valve, test of 32
Mills, F. P. 28
Mine rescue apparatus—approval of ... 5, 20
—Briggs' 5, 41
—deaths due to 17
—Draeger 17
—general construction ... 21
—Gibbs'... 17, 42
—leakage tests ... 19
—liquid air ... 5, 22
—marking of ... 23

Digitized by Google

PAGE.

Mine rescue apparatus—Meco 19, 25, 28
—Official test of 20
—Proto, 17, 18, 19, 20, 23, 25, 28, 33, 36
—standardisation of 5
—testing of 5, 20, 51
—Tissot 10, 30, 42
—valves .. 29
—Weg 17, 35, 42
Mine Rescue Apparatus Research Committee, First Report 5, 7, 8, 18, 19, 25, 35, 45, 54
Mouthpiece 50
Mueller valve, test of 31
Muscles, oxygen supply to ... 10

Newliston mine accident 17, 18
Nitrogen—accumulation of ... 42
—from the blood ... 8
Normal load 11
Nose clip—Briggs' 51
—construction 23
—danger 18
—German form 34
—Hopwood's 34
—Swansea 34

Overload 11
Oxygen—consumption during exertion 14
—consumption tables ... 15
—cylinders, rusting of ... 25
—drying of ... 27
—feed, emergency ... 51
—purity 25
—Research Committee ... 5, 27
—secretion... 9
—supply to muscles .. 10
—transference to blood ... 9
—want, effects of ... 9

Penman, D.... ... ... 6, 27
Periodic breathing 9
Physical exertion 10
—fitness 6, 12, 54
—test station 6, 12, 54
—work, nature of ... 11
Physiological considerations ... 7
Pike's Peak expedition 9
Positive pressure 19, 48
Proto rescue apparatus 17, 18, 19, 20, 23, 25, 28, 33, 36
Purifier, Briggs' 45
—exhaustion test on ... 53
—insulation 47
—test 21

Qualification of instructor ... 23

Raper, Lt.-Col. 6, 34
Reducing valve, choking of ... 28
—single lever ... 44
Relief valve... ... ... 21, 49

PAGE.

Rescue apparatus, *see Mine Rescue Apparatus.*
Rescue apparatus—men, testing of 13, 54
—station instructor, qualification of 23
Resistance, breathing against ... 9
Respiratory control 7
—fatigue 10, 11
Richardson, A. 6
Rosling, C. 6, 46, 51
Rosling valve 31, 48, 54
Rubber-disc valve, test of ... 31
Running tests 13
Rusting of cylinders 25

Saliva trap 49
Secretion of oxygen 9
Senghenydd explosion 37
Sherardising process 26
Smoke helmet 37
Sodium sulphate cooler 24
Split-tube valve, test of 31
Standardisation of rescue apparatus 5
Sunk-spindle valve... 43
Swansea rescue station 34

Testing—for leakage 19
—of rescue men 23, 54
—rescue apparatus 5, 20, 51
Tests, climbing, walking and running 13
Thery valve, test of 30
Three-compartment bag 24
Tissot rescue apparatus ... 10, 30, 42
Training gallery test 22
Trevorrow, H. 43
Tricolising process 26

Valve—mica disc 32
—Mueller 31
—relief 21, 49
—Rosling 31, 48, 54
—rubber disc 31
—split tube 31
—sunk spindle 43
—Thery 30
Valves—rescue apparatus... ... 29
—slip of 29
Varnishing cylinders 26

Walker, H.... 19
Walker, W. 3, 44
Walking—most economical rate of 17
—tests 13
Wallyford colliery fire 20
Water test 19
Weg rescue apparatus ... 17, 35, 42
Wemyss rescue station 35
Winborn, A. T. 23, 51
Winmill, T. F. 23

Zinc coating oxygen cylinders ... 27

Digitized by Google

LIST OF DOCUMENTS ISSUED BY THE DEPARTMENT.

Copies of those documents issued below which are unpriced can be obtained free of charge on application to the Secretary, Department of Scientific and Industrial Research, 16 and 16A, Old Queen Street, Westminster, S.W.1. Where a price is mentioned copies can only be obtained through a bookseller or from H.M. Stationery Office, at the addresses stated at the beginning of the list.

PAMPHLETS ON THE FORMATION OF RESEARCH ASSOCIATIONS.

Research Association 1. (*Revised.*)	The Government Scheme for Industrial Research.
Research Association 2. (*Revised.*)	Draft Memorandum and Articles of Association for Research Associations.
Research Association 3. (*Revised.*)	Conditions as to the payment to Research Associations by the Committee of Council.
Research Association 4.	The method of subscription to Research Associations.
Research Association 5. (*In preparation.*)	Suggestions on the conditions of employment of Research Workers by Research Associations.
Research Association 6.	List of Approved Research Associations.

BULLETINS.

No. 1. Memorandum on the preservation of Timber in Coal Mines. 1917.

No. 2. Memorandum on Cutting Lubricants and Cooling Liquids, and on Skin Diseases produced by Lubricants. 1918.

No. 3. A study on the performance of "Night Glasses." By L. C. Martin, B.Sc., &c. (Lecturer in the Technical Optics Department, Imperial College of Science and Technology). 1919.

No. 4. Memorandum on Solid Lubricants. 1920. Price 6*d.* (by post 7½*d.*).

CONFERENCES OF RESEARCH ORGANIZATIONS.

No. 1. Report of the meeting held on 29th July, 1919.

No. 2. Report of the meeting held on 12th December, 1919 (*with plates*). With an appendix upon the filing and keeping of information in the Records Bureau of the Department of Scientific and Industrial Research.

No. 3. Report of the meeting held on 14th May, 1920.

Digitized by Google

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

ADVISORY COUNCIL

THIRD AND FINAL REPORT

OF THE

MINE RESCUE APPARATUS RESEARCH COMMITTEE

LONDON:
Published for the Department of Scientific and Industrial Research by
His Majesty's Stationery Office and to be purchased at the addresses
named inside the cover.
1924.
Price 1*s. Net.*

Digitized by Google

PUBLICATIONS OF THE DEPARTMENT

*(Abbreviated List.)**

	Price net.	With postage.
	s. d.	s. d.
ANNUAL REPORT OF THE DEPARTMENT		
Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1922–23 (Cmd. 1937)	4 0	4 2½
TIN AND TUNGSTEN RESEARCH BOARD		
Report on the research work done under the Tin and Tungsten Research Board, 1922	3 6	3 9½
REPORTS OF COMMITTEES OF THE DEPARTMENT		
Adhesives Research Committee, First Report 1922	4 0	4 3
Gas Cylinders Research Committee, First Report 1921	7 6	7 9
Lubricants and Lubrication Inquiry Committee, Final Report 1920	2 6	2 9½
Mine Rescue Apparatus Research Committee:		
First Report 1918	2 0	2 2
Second Report 1920	2 0	2 2
Oxygen Research Committee, Report 1923..	8 6	8 9
Standardisation of the Elements of Optical Instruments, Report of Inquiry Committee on the 1920	1 0	1 1½
MISCELLANEOUS REPORTS, etc.		
Notes on the Grants to Research Workers and Students (*Revised March*, 1923) ..	0 2	0 3
On the Electro-Deposition of Iron, with an appendix containing a Bibliography of the subject, by W. E. Hughes, B.A. (Cantab.). 1922	6 6	6 8½
Science and Industry—Industrial Research in the United States of America, by A. P. M. Fleming, M.I.E.E. 1917 ..	1 0	1 2½
Report on the Sources and Production of Iron and other Metalliferous Ores used in the Iron and Steel Industry, by G. C. Lloyd, Secretary, Iron and Steel Institute. *Revised and enlarged edition*, 1918	2 0	2 3
Monograph on the Constitution of Coal, by Marie C. Stopes, D.Sc., Ph.D., and R. V. Wheeler, D.Sc. (*With plates.*) 1918 ..	2 0	2 2

* A complete list, showing prices, may be obtained upon application to the Department, 16, Old Queen Street, Westminster, S.W. 1.

(Continued on page iii of cover.)

Digitized by Google

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

ADVISORY COUNCIL

THIRD AND FINAL REPORT

OF THE

MINE RESCUE APPARATUS RESEARCH COMMITTEE

LONDON:
Published for the Department of Scientific and Industrial Research by His Majesty's Stationery Office.
1924.

Price 1s. *Net*

Digitized by Google

Digitized by Google

Heriot-Watt College
Edinburgh
6-2 3-31
39279

PREFATORY NOTE

The Mine Rescue Apparatus Research Committee, whose First and Second Reports were published in 1918 and 1920 respectively, was appointed by the Advisory Council for Scientific and Industrial Research, on the suggestion of the Home Office, in 1917, and consisted of:—

Sir William Walker, C.B.E., late Chief Inspector of Mines (Chairman).
Mr. Henry Briggs, O.B.E., D.Sc., Ph.D., A.R.S.M.
Mr. John Haldane, M.D., LL.D., F.R.S.

The experimental work of the research was conducted by Dr. Briggs at the Heriot-Watt College, Edinburgh, where facilities were provided by the kindness of the Governors of the Heriot Trust.

Department of Scientific and Industrial Research,
16, Old Queen Street,
Westminster, S.W. 1.

January, 1924.

Digitized by Google

Digitized by Google

CONTENTS

	PAGE
INTRODUCTION	1
PART I. IMPROVED LIQUID AIR RESCUE APPARATUS	2
General	2
Physical Data	2
Cost of Making Liquid Air	2
Future Possibilities in Making and Using Liquid Air and Oxygen	3
The Improved Blackett Aerophor Apparatus	4
(*a*) Brown and Mills Type	4
(*b*) The Rotherham Type	6
(*c*) The Brierley Type	7
Relative Advantages of Liquid Air Apparatus	7
The Reserve of Liquid Air at the Rescue Station	7
Testing Liquid Air Rescue Apparatus	8
(*a*) Tests for Official Approval	8
(*b*) Periodic Testing at the Rescue Station	8
Transport of Liquid Air	9
One Container per Brigade	10
PART II. THE DEWAR METALLIC VACUUM FLASK OR CONTAINER	11
Principles of the Dewar Flask	11
Materials of Construction of Vacuum Vessels	12
Construction of Metal Containers	14
Methods of Holding the Charcoal	16
Nature of the Charcoal	17
Possibility of Explosion of Charcoal in Vacuum Flasks	17
Prehensility	17
Pressure-reduction Factor	18
Drying of Charcoal	19
Decay of Vacua in Metal Flasks	20
Conduction of Heat Down the Necks of Containers	22
Losses by Evaporation due to Radiation and Conduction across the Vacuum	22
Evacuation of Dewar Flasks	23
PART III. MISCELLANEOUS	25
Compressed Oxygen Reviving Apparatus	25
Liquid Oxygen Reviving Apparatus	26
The Process of Absorption of Carbon-dioxide by Solid Caustic Soda ...	28
Training in Carrying Out Leakage Tests	29
Leakage Test for Equalizer	30
Ambulance Rooms	30
Purity of Oxygen in Cylinders which have been Hydraulically Tested ...	30

Digitized by Google

LIST OF ILLUSTRATIONS

Fig. 1. Brown and Mills Aerophor, Back View.
„ 2. Brown and Mills Aerophor, Side View.
„ 3. } Brown and Mills Aerophor.
„ 4. }
„ 5. Brown and Mills Aerophor: Rate of Evaporation from Pack.
„ 6. Steel Cradles for the Transport of Containers.
„ 7. Section of German 50-lb. Liquid Air Container.
„ 8. Vacuum Vessels for holding Liquid Air.
„ 9. Section of Porcelain Dipping Flask.
„ 10. Section of Short-necked 3-litre Vacuum Flask.
„ 11. Porcelain Vacuum Container, 25 litres.
„ 12. 300-lb. Liquid Air Storage Flask, Newcastle Rescue Station.
„ 13. Methods of making the Equatorial Joint.
„ 14. Usual Form of Joint at Bottom of Container Neck.
„ 15. Improved Joint at Bottom of Container Neck.
„ 16. To illustrate Prehensility.
„ 17. Use of Charcoal in Tubular Cartridge.
„ 18. Face-mask for Reviving Apparatus.
„ 19. Heylandt Vaporiser.
„ 20. Griffiths Vaporiser.
„ 21. Brodsworth Main Colliery: Ambulance Room and Motor House.

Digitized by Google

MINE RESCUE APPARATUS RESEARCH COMMITTEE

THIRD AND FINAL REPORT

INTRODUCTION

TO THE ADVISORY COUNCIL TO THE COMMITTEE OF THE PRIVY COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH.

GENTLEMEN,

We beg to submit our Third and final Report. It deals principally with the use of liquid air and liquid oxygen in mine rescue apparatus. We include a description of the improved Aerophor apparatus. We have entered into the problem of the construction of the vacuum storage vessels for liquid air; it is of outstanding importance to all users of the liquid, and it is also one upon which we have directed especial attention, falling—as the problem does—within the terms of reference of both the Mine Rescue Apparatus and the Oxygen Research Committees. The experimental work, the results of which are included in this Report, was carried out under the direction of Professor Briggs in the laboratories of the Heriot-Watt College, Edinburgh, and was, for the most part, undertaken on behalf of both these Committees.

In our Second Report we proposed certain methods of test for compressed oxygen rescue apparatus, and we now suggest certain modifications in those methods to make them applicable for liquid air apparatus.

A great advance has been secured by the adoption of Regulations based upon our previous recommendations, among them being those requiring all rescue apparatus for use in mines to be of an approved construction, and stipulating the nature of the tests such apparatus have to undergo.

Dr. Elizabeth Gilchrist has published a useful account of a series of experiments on the absorption of carbon dioxide which she and Mr. D. Penman carried out in 1918, when they were in your employment as assistants in the Edinburgh laboratories;* we summarise on a later page the results of that inquiry.

We take the opportunity of thanking Mr. John Mallinson, B.Sc., for the efficient assistance he rendered up to the end of March, 1921, when the experimental work of the research was brought to a conclusion; and we have once more to express our appreciation of the facilities granted for the research by the Governors of George Heriot's Trust, Edinburgh.

The Managing Committees and Superintendents of the chief liquid air rescue stations have most willingly placed at our disposal full information as to the costs of operating their plants, and we desire to place on record our appreciation of this courtesy.

Mr. E. Barnard of your Department has given us valuable help in the capacity of Secretary to the Committee.

(Signed) W. WALKER (*Chairman*).
J. S. HALDANE.
HY. BRIGGS.

* Proc. Roy. Soc. Edin.: 1921, 41, 128.

Digitized by Google

PART I.

IMPROVED LIQUID AIR RESCUE APPARATUS.

General.—The usual designation of "liquid air" apparatus is liable to misapprehension; the liquid made by the plants at the eight English rescue stations where these apparatus are used invariably contains over 45 per cent., and nearly always over 60 per cent., of oxygen. The evaporation of a part of it in the vacuum storage flasks causes an automatic enrichment of the remainder, because of the tendency of nitrogen, with its lower boiling point, to evaporate more readily than oxygen; hence the liquid actually used in the apparatus often contains over 70 per cent. of oxygen. During the evaporation of the charge placed in the apparatus a further enrichment of the residue takes place; as a result the "air" inspired towards the end of a two-hours' period may contain over 80, and sometimes over 90 per cent. of oxygen.

The plants at the stations in question are all of the so-called Heylandt principle, and were supplied before the war by the Liquid Air and Rescue Syndicate. They are—with some variation of detail—of uniform pattern, and each can give an output of 18 to 25 lbs. per hour. Generally, the higher the hourly production the lower the oxygen proportion in the liquid. At Rotherham, alone among these stations, two such plants are installed, the second to serve as a stand-by in the event of a breakdown of the first. It has been the practice at the groups of stations controlled respectively from Mansfield and Newcastle to supplement the liquid air with compressed-oxygen apparatus, in order to provide for the contingency of a failure of the Heylandt plant.

Excepting Rotherham and Brierley, the liquid air stations maintain permanent corps of men.

Physical Data.—Liquid nitrogen is colourless; it has a density of 0·81 (water = 1), and at normal pressure it boils at −196° C. Liquid oxygen is a transparent blue; its density is 1·13, and its boiling point −184° C. The temperature of the mixture in the storage flasks is usually between −186° C. and −190° C. The presence of small proportions of finely disseminated ice or solid carbon dioxide (indicating imperfect purification and drying prior to liquefaction) can be recognised by the cloudy appearance they give to the liquid.

A mixture containing 55—60 per cent. of oxygen may be considered to have the same density as water. One litre of this mixture will form on evaporation 742 litres of gas at 32° F., or 800 litres at 70° F. The equivalent figures for 1 litre of pure liquid oxygen are 790 and 850 litres.

One pound of the 55—60 per cent. mixture will yield 363, and 1 lb. of pure liquid oxygen 341 litres of gas at 70 °F.

The latent heat of evaporation of liquid air is less than one-tenth of that of water; the fact is an unfortunate one in that a considerable loss of liquid is always thereby involved in cooling a receptacle, such as the "pack" of a rescue apparatus, from ordinary temperature to the liquid's own temperature.

Cost of Making Liquid Air.—Some very low costs of manufacturing liquid oxygen have recently been published in the United States and Germany; but they relate to plants on a larger scale—some on a very much larger scale—than those required at rescue stations, and operated under different conditions and for a larger proportion of the total time. We are indebted to the Managing Committees of the chief English liquid-air stations for the following useful particulars respecting costs. Those for Station C are especially complete.

Station A.—Data based on a six months' run with a plant 10 years old.

Plant run 447 hours; made 8,705 lbs. liquid air, an average production of 19·47 lbs. per hour. Power consumption, 0·78 k.w.h. per lb. The cost, including power, repairs heavy), chemicals, oil and water, was 4·6*d.* per lb. That price, however, does not include depreciation and establishment charges; nor does it include a charge for labour. The fact that the plant is run by the station staff, which is needed in any case, is the reason for omitting the latter charge.

Digitized by Google

Station B.—Data based on a year's run. Hours of operation, 440; quantity of liquid made, 8,337 lbs., or on the average 19 lbs. per hour. Power consumption, 1·17 k.w.h. per lb. (subsequently the average output has been raised to 23·8 lbs. per hour, and the power consumption reduced to 0·91 k.w.h. per lb.). The cost, including power, repairs, chemicals, oil and water, was 2·7*d.* per lb. Depreciation on the plant at 10 per cent. per year amounted to 4·3*d.*, and establishment charges (taxes, rates, lighting, repair to buildings, insurances and proportion for management) to 4·2*d.* per lb. The total cost of making liquid air at this station was therefore 11·2*d.* per lb., wages not being included.

Station C.—Data based on a year's run. Hours of operation, 926·5; quantity of liquid made, 22,017 lbs., or on the average 23·75 lbs. per hour.

Summary of Statement of Costs per lb. Liquid Air.—

	d.
Repairs, replacements, insurance of plant, power, oil, chemicals, water...	4·53
Wages (being the proportion of the men's wages spent in running, cleaning and repairing plant)	2·37
Upkeep of vacuum flasks; lighting, heating, painting and upkeep of liquid-air room; tools	0·84
Establishment charges; proportion for rates, taxes, general insurance, stationery, etc., superintendence, cleaning, petty cash	2·11
Depreciation on plant and buildings...	3·30
Total cost per lb.	13·15
Ditto, omitting wages	10·78

Allowing 60 per cent. of oxygen in the liquid, a cost of 13·15*d.* per lb. is equivalent to 21·9*d.* per lb. of oxygen, or £7 12*s.* per 1,000 cubic feet of gaseous oxygen at 70° F.

Future Possibilities in Making and Using Liquid Air and Oxygen.—The system of having one plant (or two) at each rescue station is bound to be an expensive one in view of the small proportion of the total time any one of them requires to work, and of the depreciation charges necessary to recoup so much capital expenditure. It appears to us probable that, in those cases where there are several similar stations under a single control, it would be more economical to instal one or two plants at a central point, and to deliver the liquid to the other stations by motor lorry. We estimate, for example, that if Station C were required to turn out 90,000 lbs. of liquid air instead of 22,000 lbs. per annum—and such an output is well within its capacity—making an adequate allowance of time for repair and cleaning, the cost per lb. (including wages) would be about 9*d.*

At the time when the existing plants were installed there was no possibility of obtaining at a reasonable price machinery for making liquid oxygen of about 95 per cent. purity. This difficulty no longer exists, and small plants with an output of about 40 lbs. per hour of liquid oxygen are now obtainable. To establish a centralised plant of that character would, we believe, be a considerable step forward. Besides serving a group of rescue stations, it would be available for supplying the liquid to hospitals for the treatment of pulmonary cases, to such quarries and mines as may be permitted to use it as an explosive, and sooner or later a still wider field would probably open in connection with oxy-acetylene welding. A liquid containing only 60 per cent. of oxygen is useless as an explosive, and is of little use either for medical purposes or for welding. Moreover, almost pure liquid oxygen would be of marked advantage for rescue apparatus. Its adoption would avoid the necessity of carrying in the apparatus several pounds of useless nitrogen, as is the case at present.

So far there have been only two attempts to devise mine rescue apparatus intended to use almost pure liquid oxygen in contradistinction to enriched liquid air. The first was that of Claude of Paris*. It was a non-regenerator, quite unfitted for service when physical work had to be done. Claude claimed that when breathing pure oxygen the volume consumed by the wearer was much reduced. As we showed in our Second Report, this is entirely untrue when the man is at rest, and is only true in a much modified degree if he is physically unfit and is attempting work; for all ordinary rates of exertion the lung-ventilation of a thoroughly fit man is virtually the same on oxygen as on air.

* *Engineering and Mining Journal* (*New York*), Nov. 9, 1909.

Digitized by Google

The second liquid oxygen apparatus is that of Mr. E. A. Griffiths.* It is a regenerator having the novelty of carrying its supply of liquid air in a copper vacuum flask (the vaporiser) supported against the left side of the wearer's back. An ingenious device, which we describe later (p. 27) in another connexion, enables the delivery of gaseous oxygen from the flask to be regulated. A flow gauge is added, by aid of which the wearer may adjust the flow to the rate desired. We regret not to have had an opportunity of testing Mr. Griffiths's apparatus, but one of us has used his type of vaporiser for another purpose, and can speak of its readiness and simplicity of adjustment. The protection against mechanical injury of a metal vacuum flask forming part of a rescue apparatus requires, however, very special attention. Mr. Griffiths is to be congratulated on bringing to notice a new system of supplying a rescue apparatus with oxygen, and when almost pure liquid oxygen becomes available in mining districts his invention may prove of utility.

The Improved Blackett Aerophor Apparatus.

(*a*) **Brown and Mills Type.**—Soon after the publication of our First Report, Messrs. G. L. Brown† and F. P. Mills‡ joined forces in an extensive series of experiments, which eventually led to the production of the improved liquid-air rescue apparatus which now bears their names. Though we were not directly associated with Messrs. Brown and Mills in their research, they kept us informed of their progress, and one of us had the opportunity of taking part in several of the tests at Newcastle and Mansfield.

The apparatus is the same in principle as that described on p. 11 of our First Report, but considerable improvement has been effected in the proportion and arrangement of parts. Along with his own compressed oxygen apparatus, it was described by Dr. Briggs before the British Association in 1921, when a demonstration of the two forms was given.§

The general appearance of the apparatus will be gathered from the photographs, Figs. 1 and 2. A unique feature is the curved tube *A* (Fig. 3) which passes round the neck after the fashion of a wide collar. This arrangement serves a double purpose; it forms the means of connecting the bag to the rest of the circuit, and it enables part of the weight of the apparatus to be transferred, through pads, to the shoulders. The head-dress, noseclip, mouthpiece, saliva trap and flexible corrugated tubes, are substantially those of the Briggs apparatus,‖ a chin-guard being added to prevent the wearer dropping his chin and so exposing himself to the liability of breathing external air. The saliva trap is provided with a non-return ball valve, and is shown in section in Fig. 4. At the suggestion of Mr. J. Piggford, the straps (*S*, Fig. 4) supporting the chin-guard pass through the cheekplates in such a manner that they act as locks upon the noseclip and mouthpiece clips. The face and head fittings have been designed to make it as difficult as possible for the wearer, either wittingly or unwittingly, to draw in outside air.

The "pack" *P* (Figs. 3 and 4), or liquid air receptacle, is provided with a single, central opening for filling, which is large enough to admit the stem of the funnel and yet leave sufficient room for the unimpeded escape of gas during the operation. The liquid is soaked up in calcined asbestos wool, *W*, *W* (Fig. 3), packed tightly in a perforated case, *B*, of nickel silver. Surrounding *B* is an air space, *C*, which serves to distribute the liquid in filling, and to collect the evaporated air. The latter passes by a pipe *G* into the space *E* which is loosely packed with asbestos. From the upper side of *E* the gas flows into a metal warming pipe *H*, whence it enters the tubular collar *A*. *D* and *F* are nickel cases. The latter is insulated to retard the passage of heat into the pack by layers of magnesite asbestos *J* and of felt *K*, and by an outer laced cover of strong leather, *L*.

The space *E* serves a treble function. First, it enables the air moving through it to gain heat entering through the insulation; secondly, it acts as a trap for any liquid which, due to overfilling of the pack, may escape by the tube *G*; and thirdly, it impedes, and in a small degree regulates, the flow of heat into the interior of the pack. In the latter connexion it is to be observed that the insulation, while being sufficient to avoid too rapid an evaporation of the air, must allow enough heat to pass to boil off an adequate supply

---

* *Colliery Guardian*, 1921, 121, 945.
† Manager, North Midland Coal Owners' Rescue Stations Co., Ltd.
‡ Chief Officer, Durham and Northumberland Collieries Fire and Rescue Brigade Stations.
§ See *Engineering*, 1921, 112, 568. Since that meeting both appliances have been further improved.
‖ Second Report, p. 41.

Digitized by Google

[*To face page* 4.

FIG. 1.—Brown and Mills Aerophor. Back View.

Digitized by Google

Digitized by Google

[*To face page 4.*

FIG. 2.—Brown and Mills Aerophor. Side View.

UNIV. OF MICH.

Digitized by Google

Digitized by Google

— BROWN & MILLS AEROPHOR

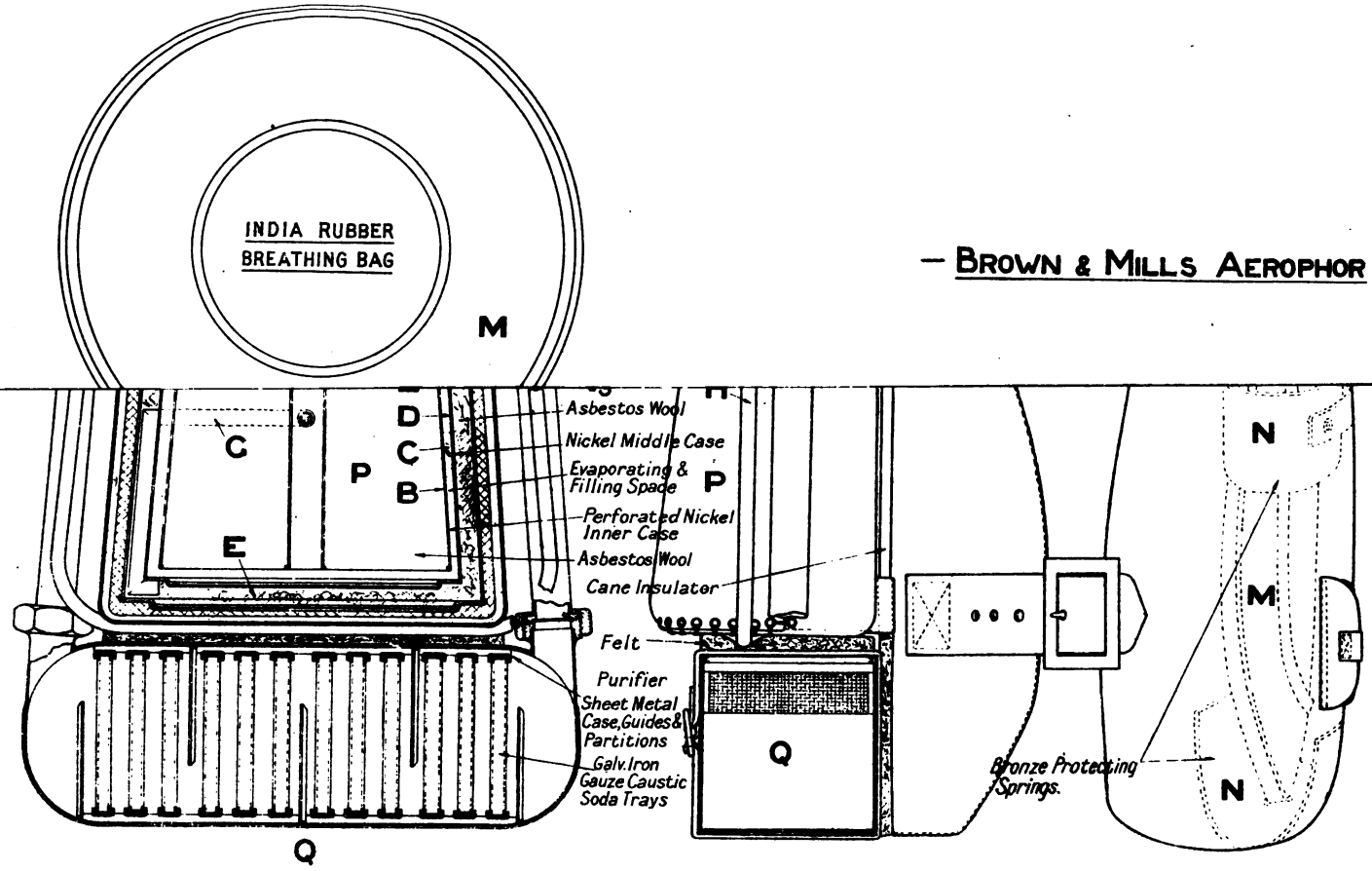


FIG. 3.

FIG. 4.

1850.113579 753 750.8 24.

Malby & Sons, Lith.

Digitized by Google

Digitized by Google

for the period of use. As illustrated by Fig. 5, in which the outflow from the pack is plotted against time, the gaseous discharge is most rapid when the pack has been freshly charged. At that part of the period the volume of cold air circulating in *E* is large, and its insulating effect is a maximum. The tendency, therefore, is at this stage for the space *R* to effect a reduction in the excessive ebullition of gas, while towards the end of a "run," when the evaporation is flagging, it is stimulated by an increase in the amount of heat passing across that space. Even with the help of this automatic means of regulation, the discharge, as Fig. 5 shows, is unequal, being as high as approximately 30 litres per minute just after pouring in the charge, and falling off to 8 litres per minute at the end of the two-hours' period.

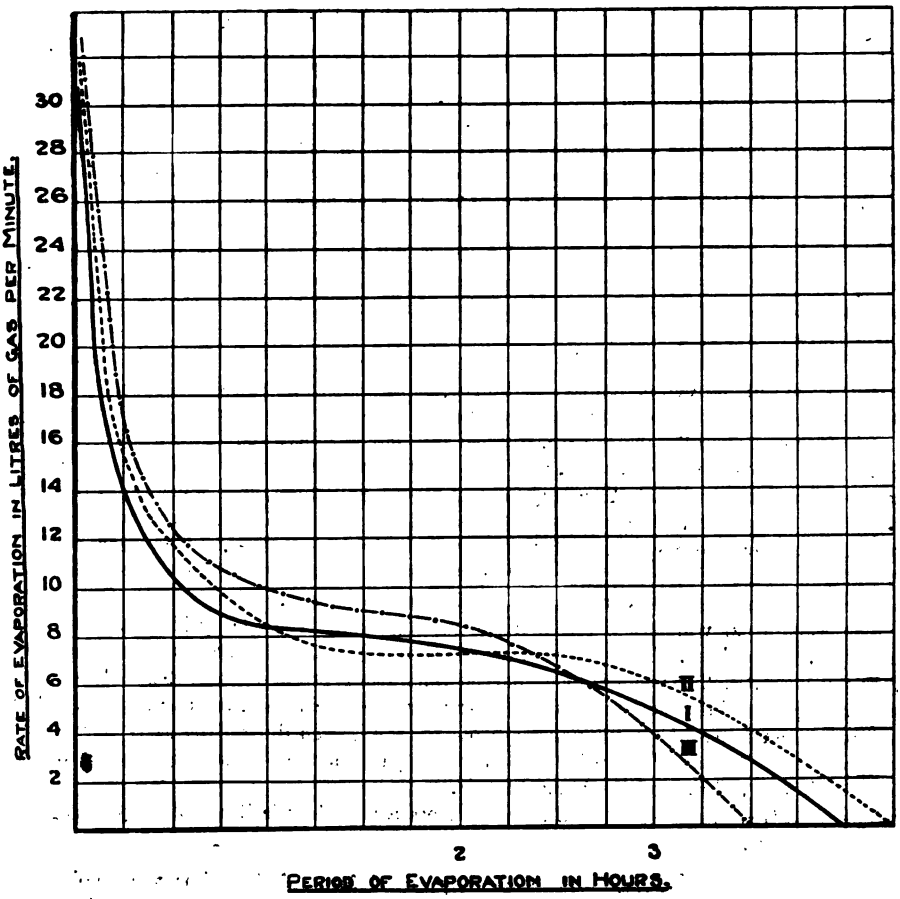


FIG. 5.—Brown and Mills Aerophor: Rate of Evaporation from Pack.

The bag *M*, which is protected by a canvas cover, is roughly circular in shape and 6 litres in capacity. To protect the bag against being crushed flat, strong curved bronze pieces *N* are fixed inside the cover and encircle the bag at the bottom and sides. The wearer, lying face downwards, can rest the whole weight of his body on the bag and still be able to breathe comfortably.

The breathing circuit consists mainly of solid-drawn brass tubing, 1 in. in diameter. All joints are made by strong, coarse-threaded screws, tightened by means of a key. Inhalation and exhalation valves, V_1 and V_2, Fig. 3, are identical in design; each consists of a thin rubber disc, secured by a central rivet to a seat of thick rubber. The seat is perforated in the manner illustrated in the plan of the valve (Fig. 3). Tests of this type of valve have been made and have shown that it is as low in slip, and even slightly lower in resistance, than the Rosling valve described in our last Report. For rescue

apparatus purposes it is preferable to the Rosling valve, owing to the greater simplicity, and smaller size of the valve box. The thick rubber seat acts as the valve's washer, while, should the valve be inserted wrong way up, attention is at once called to the mistake by its refusal to open. The excess of air delivering from the pack during the first part of a run is so large that, unless the wearer is working hard, a part of it would tend to flow back through the purifier to reach the relief valve *R*. Such a reversed flow would be detrimental in that it would cool the caustic soda and render it chemically inert. Later on, therefore, when the purifier was required to come into action, it would be inactive until it had been warmed by the expired air. Reversed flow through the purifier is altogether obviated by the inclusion of the valve V_3, which is of the same form as V_1 and V_2. The relief valve *R* is set to operate at about 3½ ins. of water pressure. It is provided with a detachable screw cap (shown by dotted lines), which is attached before the apparatus is subjected to a water test for leakage.

A low resistance to breathing is a physiological necessity for any rescue apparatus; with the liquid air apparatus, where the relief valve is between the mouth and the purifier, it becomes in addition a physical necessity. If the resistance of the purifier *Q* exceeds the resistance to opening of the relief valve, the exhaled air will pass out by the latter; the apparatus will become depleted of air, and the wearer will be compelled to reduce his rate of exertion, or, in an extreme case, to cease using the apparatus. For these reasons care has been taken by the inventors to bring down the resistance of the circuit, and especially that of the purifier, to a minimum. At first the ebullition of gas from the pack is so rapid that the wearer's needs are satisfied without it being necessary to re-breathe any part of the air exhaled; so, for a short time, the purifier is not needed, and during that time the air exhaled, together with any excess from the pack, passes out by the relief valve. After the rate of discharge from the pack has become less than the volume demanded by the lungs, the apparatus becomes a true regenerator; an increasing proportion of the expired air passes through the purifier and is re-breathed. The purifier consists of a metal case, divided internally by five baffles to obtain a zigzag flow. Between each pair of baffles, as Fig. 3 shows, there are three trays, between which the air flows "in parallel." The trays are of strong galvanised iron gauze, and together hold 2 lbs. of caustic soda granules. Pieces of thick felt insulate the purifier from the liquid air pack on the one hand and the wearer's body on the other. The wearer's back is insulated from the liquid air pack by the canvas jacket supporting the whole apparatus, and by an additional guard consisting of vertical strips of cane.

The apparatus, which has received official approval, is made by Messrs. Guest and Chrimes, of Rotherham. The approved charge of liquid air is 5½ lbs., and that of absorbent in the purifier 2 lbs. The weight of the charged apparatus is not more than 40 lbs. The liquid air can be poured into the pack and the filling vent closed in less than one minute. Care has been taken to avoid the inhaled air being too cold, even during the early part of the period of use. During the official test of the apparatus the lowest temperature of the inspired air was 70° F., and the highest 90° F.

The operation of filling a liquid air pack from a container is illustrated by Fig. 19 of our First Report.

(*b*) **The Rotherham Type.***—The second approved form of Aerophor was evolved by Mr. E. Elliston at the Rotherham Rescue Station. It closely resembles the original type described in our First Report, but the following changes have been effected:—

(1) The purifier is much larger, being cylindrical in shape, 7½ ins. long and 6 ins. in diameter, and holding 2½ lbs. of caustic soda granules. The air enters the purifier along its axis, and then is made to travel along a number of concentric cylindrical paths of gradually increasing diameter arranged in series. (2) Leather guards are fitted to the bag to prevent it being flattened by pressure. (3) The delivery pipe from the pack has been lengthened to obtain a better warming of the air before allowing it to enter the breathing circuit. (4) Hexagon unions are used instead of the original milled screws. (5) A screw nose-clip has been adopted. (6) The relief valve (which is set to blow off at 3 ins. water pressure) is provided with a screw cap for use during the water test. The approved charge of liquid air is 6½ lbs., and the apparatus, fully charged, weighs not more than 40 lbs. The pack can be filled in 1 minute. This apparatus also includes an auxiliary attachment by

* Also see E. C. Elliston, "Rotherham Rescue Apparatus," *Colliery Guardian*, 1922, 124, 329.

Digitized by Google

means of which a second person may be supplied with air, so that a man not provided with apparatus may be brought through an irrespirable zone.

(c) **The Brierley Type.**—Another variant of the aerophor, developed and used at the Brierley Station, has recently (1923) been approved.

Relative Advantages of Liquid Air Apparatus.—The outstanding advantage of the Aerophor is its great simplicity in use. The wearer has nothing to adjust and nothing to read; more so than with any other existing form, he is free to devote his whole attention to the work in hand. Having witnessed the filling of the pack, he is sure that he has a sufficient supply for at least two hours of hard work. The only gauge a rescue party needs is the alarm watch carried by the leader. No apparatus is so easy to learn, and by the boiling off of the charge the apparatus gets a little lighter during the period of use. The complete absence of high-pressure parts is in itself a recommendation.

A drawback of existing forms of liquid air apparatus, excepting Griffiths', is that once introduced the liquid boils away whether the apparatus is being used or not, while a cylinder of compressed oxygen can be kept closed until it is needed. Thus, when a spare team is "standing by" at a fresh air base while another team is acting beyond the base, the apparatus of the former have to be in operation all the time, for if they were allowed to stand empty they could not be filled and donned sufficiently quickly if a call for assistance were received.

To construct a rescue apparatus appliance which has no drawbacks is, however, outside the bounds of possibility, and it cannot be denied that the Aerophor in its recent forms has—considering the apparatus apart from the system—exceptionally few defects.

The main disadvantage of liquid air in its application to mine rescue work lies in the manufacture, storage and transport of the liquid. The manufacturing plant is costly and not easy to operate. Even when no practices are being conducted, the plant has to be worked at intervals to make up the loss by evaporation in the reserve of liquid kept in storage flasks. The storage flasks themselves are not robust articles; they give little trouble during quiet use in a rescue station, but during transportation, whether at the surface or underground, they call for special care in handling or their casualty rate is high.

The Reserve of Liquid Air at the Rescue Station.—The regulations require at least a two days' supply of liquid air to be constantly kept at the rescue station. We have remarked above upon the need, in a rightly organised operation with liquid air apparatus, of supplying a second team with liquid while one team is working. Allowing a "container" for each brigade (see p. 10), and assuming the operation to require one brigade after another for two days, the consumption during that period would be 48 containers, or about 2,400 lbs. of liquid. During the same period a single plant at a station, working 20 hours per day, would make about 800 lbs. The Mansfield group has three such plants, and thus would be able to cope with such an emergency, taking into consideration the quantity in stock at each station at any time, and provided that a sufficiency of flasks—say, six per station—were available for transport. If the circumstances were such as to require more teams than one to be continuously at work, even this group would be unable to cope with them without falling back upon compressed oxygen apparatus. The Newcastle group has at present only two of these plants, and is thus less favourably situated. We understand, however, that it it is intended to add other plants shortly. In any case, both the Newcastle and Mansfield groups have a reserve of compressed oxygen dresses.

The position at the Rotherham and Brierley stations is less favourable; they have no similarly equipped neighbouring stations upon which to call, and at present have no auxiliary compressed oxygen dresses. A 40 hours' run of the two Heylandt plants at Rotherham would yield about 2,000 lbs. of liquid; with a reserve of eight full containers and three or four empty ones in good condition, it would thus be possible to keep single brigades at work, and stand-by brigades at the fresh air base, for two days of uninterrupted labour. The station's supply of containers is such that it can maintain this stock of liquid, but a more extensive rescue or recovery operation could only be carried out by getting other stations to assist. Brierley, with its single plant, is in a still less satisfactory position.

We earnestly direct the attention of the Managing Committees of all the liquid air stations to this important issue. Possibly the arrangement of a co-operative scheme may meet the difficulty.

Digitized by Google

Testing Liquid Air Rescue Apparatus.—We limit our observations under this head to apparatus in which the liquid is carried in a receptacle other than a vacuum flask.

(*a*) **Tests for Official Approval.**—When a liquid air apparatus is submitted for approval it should undergo the endurance and gallery tests now laid down in regulations, and the safeguards provided therein against defective workmanship and design should also apply. The stipulation as to a maximum resistance of the breathing circuit needs no alteration.

The provision of anything having the effect of a by-pass on apparatus of this class is a matter of much difficulty, and if care be taken that there is at all times during use a copious supply delivering from the pack, we think that such provision need not be required.

We have unfortunately not been able to reach unanimity in regard to the minimum feed of oxygen that it is desirable to prescribe for liquid air apparatus, and we think it advisable to state both the views which have emerged in the course of our proceedings:—

Sir William Walker and Professor Briggs.—"With apparatus such as this, in which there is no by-pass, it is necessary, in our opinion, to ensure, at all parts of the period of use, that there shall be a supply of oxygen appreciably exceeding 2 litres per minute. The end portion of the period, when the delivery of 'air' from the pack is a minimum, may happen to coincide with the time when a brigade (returning perhaps from dip workings) is demanding an unusual supply of oxygen. Should that supply be only 2 litres per minute, the men would be obliged to slow down or otherwise reduce their rate of exertion to conform with the limitations of the apparatus. We believe that it would be preferable to reduce the chance of such an incident by the provision of a 'factor of safety' of 50 per cent., and that the minimum permissible rate of discharge of oxygen during the 2-hours period of use should be 3 litres per minute. Earlier in the history of rescue apparatus in this country, the user was compelled to suit himself to the apparatus. Our view, from the commencement of the research, has been that a rescue apparatus, to be of real service, should suit itself to the requirements of the wearer, and we do not see the need to recommend anything contrary to that principle on this occasion."

Professor Haldane.—"The present regulations require that, in compressed oxygen dresses having a constant feed, the delivery of oxygen shall not be less than 2 litres per minute. I consider that a similar requirement is sufficient in respect of a liquid air rescue apparatus. If the supply of oxygen at the end of a working period is 2 litres per minute, that supply will be exceeded, and usually greatly exceeded, for earlier parts of the period. While it is true that the 2 litres of oxygen may be diluted by a considerable proportion of nitrogen, it has been found by experiment that, if a man is getting 2 litres of oxygen per minute, he will not suffer collapse, even though his lungs should, for a short time, require a greater supply for the work he is attempting. In such a case he would be compelled to cease or reduce the work by the excessive panting which would supervene. On the other hand, when the feed is much below 2 litres, a call for oxygen in excess of that amount may cause the wearer of a rescue apparatus to drop unconscious without much warning. With a two-feed litre feed then, though a good deal of nitrogen be also present, an adequate warning is given by the panting which develops on over-exertion. In view of this I recommend that the oxygen supply in liquid air rescue apparatus should be regarded as sufficient if, at the end of the two hours' period, the delivery contains 2 litres of oxygen per minute."

It is desirable that the pack or receptacle should be so constructed that there will be no chance of liquid air getting into the breathing circuit, and as a test we think the pack should be inverted one minute after receiving the approved charge, when no liquid should run out of the open filling vent or of any other opening.

We consider also that the wearer should be protected against the possibility of the inspired air being so cold at the beginning of a "run" that the inspiration valve freezes, and to that end it could be required that at no time should the inspired air be at a temperature lower than 25 deg. F. below that of the place in which the official tests are conducted.

(*b*) **Periodic Testing at the Rescue Station.**—In the Aerophors now approved the leather cover of the pack is the only protection the insulation has against wet. Such a pack cannot be tested for leakage by immersion in water; hence, in carrying out the prescribed water test, it should be required to test under water all parts except the pack.

Digitized by Google

At the same time it is to be regretted that this exception has to be made, and it seems to us that a sealed metal case, either instead of the leather cover or immediately under that cover, would be of advantage, both in respect of simplifying the water test and of improving the protection of the insulation. A polished metal case outside the pack would itself reduce the heat inflow to the receptacle; moreover, inside such a case the pack would no longer be subject to the possibility of a deterioration of its insulation were it required to work, spell after spell, in a wet place.

To provide the means for observing deterioration of the absorbent filling of the pack, it is desirable to require that at, say, two-monthly intervals, each pack should be tested by inverting it one minute after pouring-in the approved charge, when no liquid air should flow out of the open filling vent or of any other opening. In the event of a pack failing to comply with this test, its absorptive packing should be changed.

Transport of Liquid Air.—Experiments have from time to time been made to ascertain the loss involved in carrying liquid air containers on lorries and on rail.

Some years ago a container charged with 50¼ lbs. of liquid air was packed with paper padding inside a pyramidal wooden box, and sent unattended on a railway journey covering approximately 320 miles. In addition, it travelled 11 miles by motor wagon. The time taken, including one overnight stay, was 36 hours. The rate of evaporation of the bottle under tranquil conditions was 3½ lbs. per day, or 66 grams per hour. The rate during the whole journey (including the overnight rest) was 5¼ lbs. per day, or 103 grams per hour. Correcting for the loss while standing overnight, the actual loss while travelling was at the rate of 6·1 lbs. per day, or 114 grams per hour. Hence the rate of loss during rail transport was 1¾ times that when standing still. The container was of the usual German design (see Fig. 7), and had no buffer pads in the vacuum space. The movement of the train would therefore constantly cause touching of the inner against the outer sphere, with transference of heat at each contact.

A short but useful test upon transporting containers by motor wagon was made by Dr. Briggs and Mr. G. L. Brown at Mansfield. Two containers were taken a run of 7·6 miles over good roads in a heavy motor ambulance. The journey took 27 minutes. Each bottle held 50 lbs. of air at the start. The first container stood on the floor of the wagon, being merely prevented from sliding about by a wooden guard ring fixed to the floor. The second vessel was provided with trunnions (see No. 1, Fig. 8), which were carried in bearings on a special stand, so that the bottle was able to swing under an impact and to right itself immediately after. The bearings were supported on springs with the intention of still further reducing shock. The first bottle lost 7 ozs. on the journey and the second 14 ozs. The vessel in gimbals was caused to swing violently by the movement of the wagon, with continuous rapid boiling of the air and frequent spurting of liquid from the neck. The springs only accentuated the motion. The rigidly-held vessel was comparatively tranquil, though the inner sphere was constantly heard bumping against the outer one.

As the result of this test gimbal support was entirely given up for motor transport.

Mr. Brown continued to work on the problem, and eventually found nothing so suitable for the carriage of containers in wagons of any description as the simple steel stand of which two types are depicted by Fig. 6. The cradle is provided with handles to facilitate underground transport. With these stands some remarkably efficient journeys have been made by road. In one instance a container was run by the rescue car to a colliery and back, a distance of 28·8 miles; 1¾ hours were spent on the road. Making a deduction for evaporation while the vessel was standing at the mine, the loss during transport was 3·14 ozs. per hour. Standing quiet the bottle lost 2 ozs. per hour. During road transport then, the evaporation rate was 1·57 times that when stationary.

Having regard to the fact that, in actual service, containers holding a full charge of at least 50 lbs. will have to be carried, it would, we consider, be advisable to reckon upon a loss during road transportation equal to 2½ times the equivalent loss under stationary conditions, while the evaporation rate during an average underground journey will, in all likelihood, be more. The provision of asbestos pads in the envelope (p. 15) and of a splash ring (p. 16) will improve the efficiency of transportation.

Special bogies, running on the mine rails, are employed on the Continent for the underground transportation of containers carrying liquid oxygen for use in blasting. One such carriage, illustrated in the *Colliery Guardian*,* consists of a framework of T-section

* "The Use of Liquid Air for Blasting," *Colliery Guardian*, 1920, 120 656.

Google

steel, from which hang two containers. Each vessel is slung by two chains provided with spring shock absorbers. The amount of movement permitted, however, appears too large, and for reasons already given we do not favour support on springs. The fact that the bogie has a height of 2½ times the gauge of the rails is a serious drawback in low mines.

One Container per Brigade.—For ease of transport and organisation, it is evidently advisable that the aerophors of a brigade of five should be supplied from a single container, and it is worth while to ascertain whether this is practicable with two of the approved types. The first fill of a pack is the most wasteful, as the pack has to be cooled to liquid air temperature. Where a second spell of work succeeds immediately after the first, the loss in refilling is small.

An aerophor pack, taken at room temperature, can be filled at a rescue station with a loss of under 2 lbs. of liquid air; but in the circumstances obtaining at a fresh-air base, where the filling is likely to take place in the event of actual service, it is advisable to allow for an additional waste of ½ lb.

The Brown-Mills Aerophor requires a charge of 5½ lbs; to get that amount into a pack which starts warm, 8 lbs. per apparatus would need to be poured from the container, or 40 lbs. would be required for a team of five. From what has been ascertained regarding the efficiency of transport, it would appear that, under careful handling, the loss between the rescue station and the fresh-air base—even if they are 20 miles apart—should be under 1 lb. This apparatus can thus be supplied by one container per brigade and allow of a margin of safety of 18 per cent. If necessary, a sixth apparatus could also be filled. The margin for the second and subsequent spells of work with the same packs will be considerably greater.

The Rotherham aerophor uses 6½ lbs. per charge. Starting with warm packs, 45 lbs. would be needed for five apparatus. Allowing for 1 lb. being lost in transportation, the margin on 50 lbs. load will be about 8 per cent. There will thus be a sufficient excess with either form of aerophor to allow for contingencies and to keep the container cold on the return journey.

Digitized by Google

[*To face page* 10.

FIG. 6.—Steel Cradles for the Transport of Containers.

FIG. 8.—Vacuum Vessels for holding Liquid Air.

Digitized by Google

Digitized by Google

PART II.

THE DEWAR METALLIC VACUUM FLASK OR CONTAINER.

Principles of the Dewar Flask.—Everyone is now familiar with the "thermos" flask, a double-walled glass flask in which the space between the two walls has been evacuated, in order to reduce to small proportions the heat conducted across it. The inner surface of the outer, and the outer surface of the inner vessel—the two surfaces which face each other across the vacuum space—are silvered. The two opposing reflecting surfaces have the effect of greatly diminishing the transference of heat from one to the other by radiation.

Attention is directed to the recent report of the Oxygen Research Committee,* which deals in considerable detail with the development of the vacuum flask. In what follows we shall give a general description of vacuum flasks used for mine rescue purposes, and a short account of investigations which we have initiated, either independently or in conjunction with the Oxygen Research Committee, to elucidate points of special interest to those connected with mine rescue work.

The two chief causes of heat transfer in a vacuum flask are *radiation* and *conduction across the vacuous space*. We state them in what is, in general, their order of importance. There are other minor sources of heat transfer, but these may be disregarded at this stage. Sir James Dewar described the metal vacuum bottle in 1906,† having the previous year obtained a patent for his famous invention of augmenting or preserving a high vacuum in flasks intended to hold *cold* liquids. The vacuum of a well-made glass flask appears to remain intact indefinitely, so long as the bottle is saved from mechanical injury; but no metal vacuum bottle can be made altogether impervious, and in the course of time the original vacuum becomes vitiated by gas entering it from outside or inside the bottle. But for Dewar's method of absorbing the greater part of the gas in the vacuous envelope by means of charcoal, that gas would soon spoil the insulating property of the vacuum; indeed, metal vacuum vessels would be out of the question.

The absorbent charcoal is supported within the vacuous envelope in such a position that it quickly attains the temperature of the cold liquid poured into the bottle. Thus in Fig. 7, which is a section of a German liquid air container, the charcoal is held inside

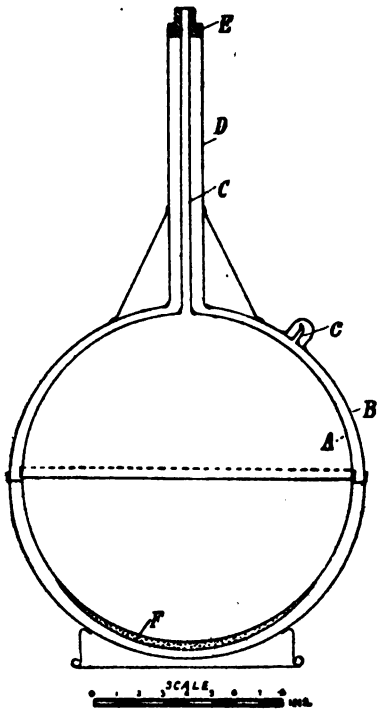


FIG. 7.—Section of German 50-lb. Liquid Air Container.

Published by H.M. Stationery Office, 1923. Price 8s. 6d. net.
Proc. Roy. Inst., 1906, 18. 439.

Digitized by Google

a dish-shaped metal spinning, *F*, attached to the lower half of the cold inner flask. The charcoal is connected to the vacuum space by means of one or more openings in the dish, the openings being covered by fine gauze. The absorptive or, as it is usual to say in such a connection, the *adsorptive* power of the charcoal (that is, its affinity for gas) is greatly increased by cold, and at liquid air temperature it is very strong. Thus, when cooled to that temperature, it draws into and retains within its own substance the gas existing in the vacuum space, and therefore automatically preserves the high degree of vacuum needed.

It may be claimed for Dewar's system of using charcoal for this purpose that, more than any other single cause, it has rendered possible the expansion now proceeding in the scientific and industrial uses of liquid air and liquid oxygen.

Dewar experimented on the adsorptive properties of other porous substances as well as charcoal. He found, for example, that dry alumina possesses at low temperature a considerable power of absorbing air at atmospheric pressure, but that owing to its relatively low "retentive power"—or, as we now prefer to say, its low *prehensility* (see p. 17)—it is much inferior to charcoal in forming high vacua.* In a second patent specification, dated April, 1905, he refers to the application of earthy oxides (alumina, silica, ferric oxide, etc.) for the absorption, especially at low temperatures, of gases and vapours. Later in this report we shall have occasion to refer briefly to the feasibility of using such substances, particularly silica, as a substitute for charcoal in Dewar flasks. The matter receives more complete treatment in the report of the Oxygen Research Committee.

Materials of Construction of Vacuum Vessels.—In present day practice the use of charcoal in the vacuous space is limited to vessels of metal. With the other materials here mentioned there is little or no need for charcoal.

The greater number of the containers at British rescue stations are German-made pre-war vessels. So far as our observations have gone, these German flasks are of brass, in the manufacture of which alloy, in its finest grade, the Germans are unrivalled. Since the war the Germans have constructed containers of copper, and during the war they made satisfactory flasks (chiefly of small size) of steel.

Though other metals and alloys have been used on the experimental scale, the majority of the liquid air bottles made in this country during and subsequent to the war are of copper. That metal is capable of receiving a high degree of polish. It is easily spun and soldered, and its one detrimental property, namely, softness, can to a large extent be offset by proper protection of the vessel during transport. Moreover, with the sole exception of silver, copper is the metal which, at a well-polished surface, has the highest reflecting power for heat rays.

Gilding metal takes an exquisite polish and solders well, and a number of excellent vessels have been made from it. The copper-tin variety, however, is harder than copper and requires special tools in spinning. As a result, the cost of a flask made of this alloy exceeds that of one of copper.

Whatever the metal, the sheets from which the hemispheres are spun or pressed should be free from blemish. Pitted sheets should not be employed, as the acid "pickling" used in cleaning the sheets of oxide is apt to lodge in the small cavities and set up slow corrosion.

To reduce the amount of heat conducted from the outside air down the inner neck (*C*, Fig. 7) to the liquid air in the bottle, it is usual to employ, as the inner neck of a metal flask, a piece of solid-drawn tube of an alloy having a low thermal conductivity. The Germans use both manganese steel and German silver for this purpose, while in the containers made recently in this country cupronickel (about 36 per cent. nickel, 64 per cent. copper) has been adopted for the purpose. Though the conductivity of cupronickel exceeds that of German silver and is almost equal to that of brass, the heat inflow to the liquid is not appreciably increased thereby, for, as will be shown, the heat reaching the liquid *via* the neck is, with long-necked vessels, negligibly small in amount.

Fig. 8 is a photograph of a number of vacuum vessels. No. 6 is a thermos flask. No. 7 is a glass vessel of a type familiar in laboratories where liquid air is handled in small quantities. Nos. 1 and 2 are 50-lb. containers, the first being a brass bottle of German make (sectioned in Fig. 7), and the other a gilding metal bottle with a shorter neck surmounted by a loosely fitting brass cap insulated within by felt. No. 5 is the 3-litre

* *Proc. Roy. Inst.*, 1906, 18, 433.

Digitized by Google

gilding metal vessel, a section of which is given in Fig. 10. Thirty of these "vaporiser" flasks were lent to us by the A.M.D., War Office, and have been most useful in our experiments. Nos. 4 and 5 are porcelain "dipping flasks" made at the State Porcelain Factory, Berlin, during the war. No. 4 shows the flask inside its protective case of galvanised sheet iron, and No. 5 the bottle itself, mouth downwards. Fig. 9 is a section of one of these porcelain vessels, showing the case *D*; a packing of corrugated paper *C* between the

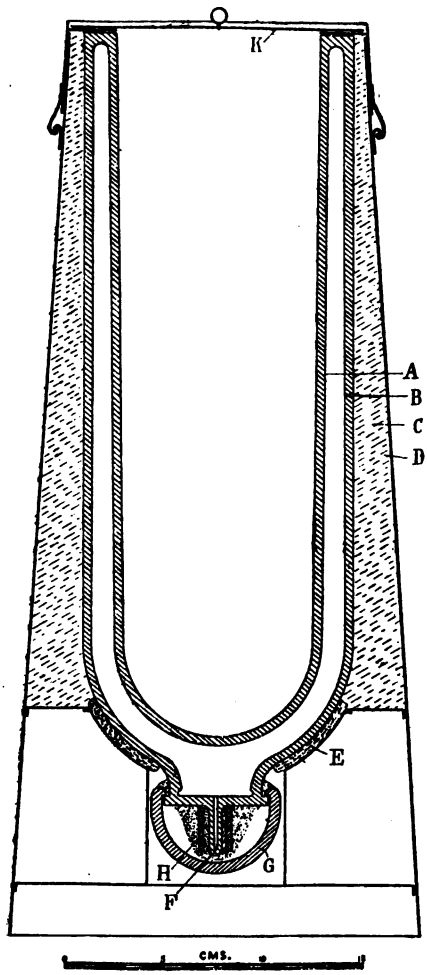


FIG. 9.—Section of Porcelain Dipping Flask.

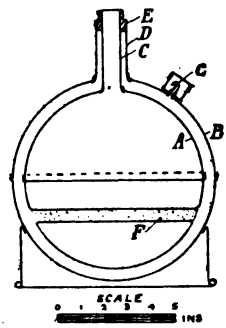


FIG. 10.—Section of Short-necked 3-litre Vacuum Flask.

Digitized by Google

case and flask; the loose cover (a disc of galvanised iron) K; the double-walled and almost parallel-sided flask A, B; the sealing tube F; and the porcelain cup G, which is attached by plaster-of-paris over the sealing tube to protect it. The sealing tube is of porcelain, and after the evacuation it was sealed-off by an oxy-hydrogen flame. The porcelain is highly vitreous, and although the vacuum is not so permanent as that of a glass flask, it lasts a considerable time. The internal diameter of the bottle illustrated is 4 ins., its depth 14 ins., and its capacity 6½ lbs. It was designed for service in connection with the use of liquid oxygen as a blasting agent. The wide mouth allowed of several cartridges of carbonaceous material being lowered in and saturated with the liquid.

The large porcelain bottle of Fig. 11 (which shows the metal case and the porcelain flask removed from the case) was also made in Berlin. Its capacity is 25 litres, its external diameter 14 ins., and its depth 28½ ins. The mouth is $\frac{15}{16}$ in. across. On being tested by Mr. F. P. Mills at Newcastle, it was found to have an evaporation rate about 2½ times that of a good metal container of the same capacity. The reflecting surfaces surrounding the vacua of these porcelain flasks are deposited films of metallic silver. Attempts to construct similar vessels in France and Scotland were not successful. Their manufacture has for the time being ceased in Germany, metal vessels being found lighter and cheaper.

Small vacuum flasks of silica-ware have been made in England, but its relatively high price stands in the way of the silica bottle becoming a serious rival of that of glass and metal.

Fig. 12 is of interest as showing the largest vacuum flask in use at English rescue stations. It holds over 300 lbs. of liquid air, and is employed for storage purposes at the Newcastle station. It was built in Germany before the war and is of brass; it was photographed for comparison's sake alongside an ordinary 50-lb. container.

Construction of Metal Containers.—The liquid air or liquid oxygen is held in the globe A (Fig. 7), which is suspended by the neck C so as to hang almost centrically within a second globe B. The spherical shape is used because, for a given volume, the sphere presents less surface area than any other shape. The inner and outer globes are each built up of two hemispherical spinnings or pressings, joined together by soft solder. The inner neck C is soldered into a plug E of solid brass turned from bar metal, and in turn the plug is soldered into the outer neck D of solid-drawn copper tube. The neck is strengthened by a conical collar. The vessel stands on the beaded edge of a sheet-metal ring soldered to the body.

The air between the spheres A and B is withdrawn through a pure lead tube G, preferably more than ¼ in. in bore. The lead tube, previously tinned with solder on its inside, is squeezed and malleted flat when evacuation is complete, and then burned off with a small Bunsen flame. A cup-shaped cap is put over the lead seal to protect it, the cap often being filled with bitumen or wax. In Fig. 11 and Nos. 2 and 5, Fig. 8, the seal cover is a short piece of brass tube which screws over a ring permanently soldered to the flask round the seal. A flat lid is screwed on. The latter arrangement more effectually preserves the seal against injury. As has already been stated, the surfaces of the globes which face each other across the vacuum space are highly polished. It is barely possible to expend too much attention on the burnishing of these surfaces, for, as we shall see, the greater part of the heat passing to the liquid air in the vessel is generally transmitted by radiation. Only by obtaining the highest possible polish on these surfaces, and by taking care that the polish is not impaired during the construction of the flask, can radiation be reduced.

The vacuum of a container of the design of Fig. 7 is held by seven soft-soldered junctions of which two, namely, the equatorial joints of the spheres A and B, extend together to a length of 7½ ft. (2¼ metres). Evidently then, no operation in building a flask is more important than that of soldering, and the suitability of solders and fluxes receives attention in the report of the Oxygen Research Committee.

The bore of the inner neck C, Fig. 7, is usually either $\frac{3}{8}$ or ½ in.; the latter size is preferable; it allows of the flask being filled and emptied more readily.

The German practice is to allow the inner globe A to hang freely within the outer globe B, and not to employ steadying pads or pieces extending across the vacuum space. Their reason for omitting such pads is probably not so much that they would conduct heat—for their influence in that respect can be reduced to negligible proportions—but that they would prevent the contact of the inner and outer globes in the act of pouring

Digitized by Google

FIG. 11.—Porcelain Vacuum Container, 25 litres.

FIG. 12.—300-lb. Liquid Air Storage Flask, Newcastle Rescue Station.

UNIV. OF MICH.

Digitized by Google

Digitized by Google

liquid from the flask. When the neck is only $\frac{3}{8}$ in. in bore the contact is helpful in pouring: it accelerates evaporation in the flask, and the resulting gas assists in ejecting the liquid. When the bore is $\frac{1}{2}$ in., pouring becomes a sufficiently rapid operation to make any such extra assistance of little account.

We prefer the practice introduced by the Research Department of the Air Ministry of providing four or six equally-spaced pads of calcined asbestos in the vacuum and close to the equatorial joint. The pads are fastened to the outer globe, and do not quite reach across the vacuum. There is thus no actual contact until the vessel is inclined from the vertical. The pads greatly reduce the movement of the inner vessel relative to the outer one, and by so doing lessen the strain upon the soldered connections of the inner neck. They prevent the continual bumping of the inner against the outer vessel during transportation, thus lessening the loss of liquid air by evaporation—a loss which is considerably enhanced by frequent contacts of the cold and warm globe; and, in addition, they remove the necessity which otherwise prevails for a long, flexible inner neck. We shall see that such a long, slender neck as that of the container, Fig. 7, is not needed to render heat transfer *via* the neck small in amount, and that, providing the container is fitted with buffer pads or with an equivalent device to reduce lateral movement of the inner flask, a shorter and stouter neck may be used in the interests of strength and convenience.

Fig. 13 (*a*) is the usual way of making the equatorial joints of metal vacuum flasks. We have used the kind of joint (*b*) for a few containers. Its strength is superior to that

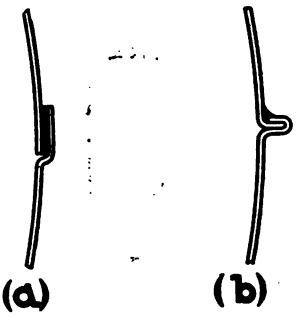


FIG. 13.—Methods of making the Equatorial Joint.

of (*a*), but it suffers from two drawbacks: it increases the cost of the flask, and prevents it being taken to pieces unless one or both of the outer hemispheres are destroyed.

The experience gained at rescue stations and elsewhere proves that of all the joints of a container none is so likely to give way as that at the bottom of the inner neck. The usual form of that joint is shown by Fig. 14. The attachment is obviously weak, having regard to the fact that the whole of the weight of the liquid and inner sphere bears upon

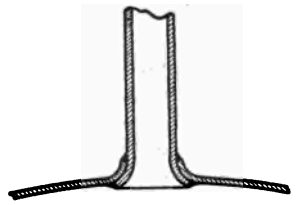


FIG. 14.—Usual Form of Joint at Bottom of Container Neck.

it, and also that the junction is subjected to sudden changes of temperature which impose strain owing to the differing coefficients of expansion of the neck-tube and the spherical body. In the container No. 2, Fig. 8, the joint in question was satisfactorily strengthened in the manner indicated in Fig. 15. The neck *A* was soldered into a flange *B*; after the hemisphere *D* had been fitted into place the clamping piece *C* was screwed on hot. All the surfaces of contact were well tinned beforehand. Other methods of connecting the neck are described in the report of the Oxygen Research Committee.

Digitized by Google

It is desirable to prevent these bottles being entirely emptied of liquid air ; a little should remain to keep the bottle cold and so facilitate refilling. It is also advisable to take precautions against the liquid splashing against the neck during transportation, or the flask is apt to lose liquid by spurting. Both objects can be secured by providing a "splash-ring" *R*, Fig. 15, or merely by continuing the neck *A* 1½ ins. into the bottle, though the latter method is inferior to the splash-ring as a means of preventing spurting.

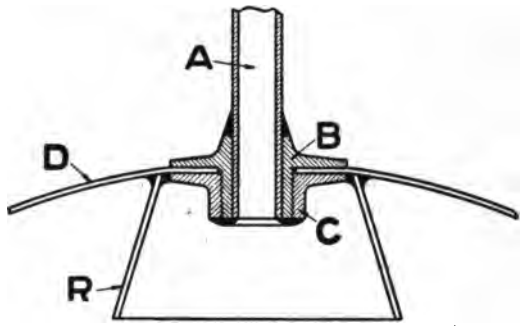


FIG. 15.—Improved Joint at Bottom of Container Neck.

Methods of Holding the Charcoal.—A method of holding the charcoal common in German containers has already been described. It consists in providing a dish *F*, Fig. 7, to support the charcoal in contact with the cold inner sphere. In this instance the dish, which is furnished with gauze-covered openings, is securely soldered to the globe around its edge, and its outer surface is polished. An alternative which has led to a number of failures is that of "tacking" a charcoal dish by solder to the inner sphere at six or eight places round the edge. The spaces between the tacks provided the necessary connection between the charcoal and the vacuum, while at the same time the fit of the dish to the globe was sufficiently close to prevent escape of the charcoal. The method was introduced to avoid the need for gauze-covered openings, but that advantage was bought at too dear a price: owing to the weakness of the tacks, the dish was apt to fall away when the vessel was in use.

It is a merit of the above methods that the charcoal may be introduced after the whole flask has been built and tested for leakage. For this purpose round holes are cut, immediately opposite each other, through the outer globe and the dish at their lowest points, the former being the larger hole. Before testing for leakage, the hole in the outer sphere is covered by a thin copper disc soldered on ; after that test the bottle is inverted and the disc removed ; hot charcoal is poured into the dish through a funnel ; the hole in the dish is closed by a gauze or disc soldered on, and, lastly, the disc is again soldered over the outer hole. Many German flasks are fitted in this way.

A method of holding the charcoal which we have found satisfactory was suggested by Dewar in 1918. It is illustrated by Fig. 10, and consists in placing the charcoal in a tube *F*, crossing the lower inner hemisphere. The ends of the tube are covered by gauze soldered on. The tube, which may be of pure lead or of copper (solid drawn), is generally bent in the plane at right angles to that of the section in order to increase its length and to avoid contact with the stem of a funnel or other tube inserted through the neck.

It has been objected that the gauzes are apt to catch in the buffing cloths, and that polishing powder lodges in them and is difficult to remove. The objection has no weight unless the charcoal is introduced and the gauzes soldered on before the polishing is completed. The charcoal, whether in this or in any other arrangement, should only be inserted at the last possible moment, or else it rapidly absorbs moisture, which prolongs the subsequent evacuation. In this case the charcoal should be left out until the flask has been completed up to the attachment of the lower outside hemisphere. The introduction of the charcoal and the fixing of the gauzes is thus followed by two operations of construction only, namely, the soldering on of the lower external spinning and of the ring bottom on which the container stands. (Also see "Drying of Charcoal," below.)

Digitized by Google

Nature of the Charcoal.—Dr. Briggs and his assistants have carried out a long series of experiments which extend our knowledge of the action of the charcoal used in Dewar flasks. The theoretical implications of these experiments have been dealt with in a separate paper* and need not be referred to here; but certain practical conclusions require to be discussed.

That charcoal employed in these flasks has been "activated"—that is to say, it has been subjected to a treatment which has greatly improved its power of dissolving or adsorbing gas. The treatment may be long-continued heating in a slightly oxidising atmosphere, heating in an atmosphere of superheated steam, or, as in modern German practice, impregnation with certain salts which yield a final product containing a small percentage of excessively finely disseminated iron or zinc.

From the present point of view the best charcoals for activation are the densest, and especially those made from cocoanut shell and fruit stones. A good charcoal—not so much used in this connection as formerly—is that of birch. The German impregnated charcoal is lighter in weight, being generally of pinewood.

Possibility of Explosion of Charcoal in Vacuum Flasks.—During the war a number of explosions took place, especially in Germany, owing to Dewar vessels containing liquid oxygen being suddenly pierced by a sharp instrument. If the construction is as Fig. 7, and the implement be driven through both spheres from below, the liquid will be sucked into the vacuum space and will drench the charcoal. So strong is the affinity of activated charcoal for oxygen that rapid chemical combination may ensue; there will then be an explosion.

The problem was explored by Professor L. Wohler,† who discovered that impregnated charcoals, particularly those containing iron, were most apt to explode in this way, and care is now taken in Germany that the charcoal used for the purpose shall be iron-free. The risk is much less with British-made vessels, since we do not use impregnated charcoal.

The danger is also less with dense coal-like charcoals, such as those of plumstone and cocoanut, than with light, flaky charcoal, such as that prepared from beech-husks. It is also much smaller with enriched air containing 60—70 per cent. of oxygen than with almost pure liquid oxygen. Again, the chance of explosion is less when the charcoal is held in a tube (Fig. 10) than when held in a dish (Fig. 7).

The probability of the occurrence of the kind of puncture able to deluge the charcoal with the liquid is slight in connection with mine rescue operations; indeed, we know of no instance in which that particular accident has happened at British rescue stations or mines. A satisfactory safeguard is to pack the container with slagwool inside a strong outer case, as is done in this country when liquid air is carried on the railway.

In view of the possible future extension of the use of liquid oxygen, experiments have been made in conjunction with the Oxygen Research Committee to find out whether any non-inflammable substance could be used in place of charcoal in these flasks, for, if so, its adoption would entirely eliminate the danger in question. The most promising of these substances was colloidal silica, and a silica was eventually made in the Edinburgh laboratories which exhibited, we believe, higher adsorptive power at ordinary pressure than any inorganic compound yet prepared. On nitrogen, at the temperature of liquid air and at atmospheric pressure, that silica had 166 per cent. of the capacity of the best cocoanut charcoal. Unfortunately, the holding capacity at atmospheric pressure has little to do with an adsorbent's power of taking in gas or vapour at very low pressure—and it is in the latter connection that the substance is required in vacuum vessels. The silica was greatly inferior to plumstone and cocoanut charcoals in its power of creating a vacuum; moreover, its preparation is lengthy and would be expensive. A description of the method of making the silica, and of many other compounds and mixtures tried in these experiments, has already been published.‡

Prehensility.—If we determine by experiment the weight of nitrogen which is taken up by one gram of adsorbent at liquid air temperature and at gas-pressures ranging from zero to 760 mm., and if we plot the data so obtained, taking pressures as abscissae and

---

* H. Briggs, "The Adsorption of Gas by Charcoal, Silica and other Substances," *Proc. Roy. Soc. A.*, 1922, **100**, 88.

† *Chemiker Zeitung*, Oct. 5, 1918.

‡ *Proc. Roy. Soc.*, op. cit., 90.

Digitized by Google

weights adsorbed as ordinates, a curve resembling *A*, Fig. 16, is obtained for cocoanut charcoal, and one resembling *B* for the silica just referred to. Now we give to the charcoal of the Dewar vessel the duty of reducing a pressure already rendered small by pumping to one which is smaller still. Clearly, what matters in that operation is

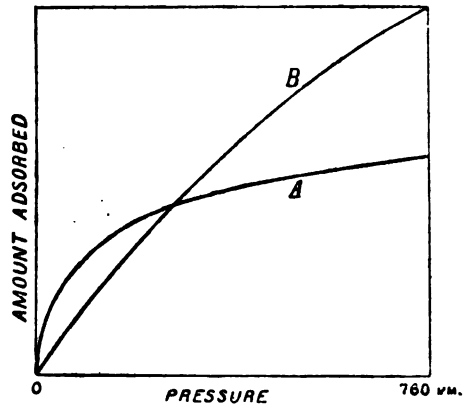


FIG. 16.—To illustrate Prehensility.

the form the curve takes at, and close to, the origin. The evacuating power of an adsorbent is, indeed, indicated by the *slope* at the origin of its isotherm (*e.g.*, *A* or *B*, Fig. 16) for the particular gas at the particular temperature. The substance giving curve *A* is more useful in evacuation than that giving curve *B*.

The slope of an isotherm at its origin has been termed the *prehensility* of the substance for the gas and conditions expressed by that curve.*

Pressure-reduction Factor.—A problem met with in connection with Dewar vessels is the vacuum produced by the charcoal when it is cooled to liquid-air temperature, the pressure having been reduced to a known value prior to the charcoal coming into action; or, again, we may wish to ascertain how far the preliminary evacuation ought to be carried to enable the charcoal to bring the pressure down to a desired point. An approximate though useful solution of such problems is now possible as the outcome of the experiments of Lambert and Briggs. If P be the pressure existing in the envelope of a Dewar flask before liquid air is poured in, and p be the pressure after the liquid is introduced and the adsorbent has come into action, the ratio of the initial and final pressures in the space, *i.e.*, $\frac{P}{p}$, is spoken of as the *pressure-reduction factor*, *f*.

Major Lambert, of Oxford, carried out for the Oxygen Research Committee a series of valuable experiments on charcoals and some inorganic colloidal adsorbents, in which tests a known volume of one of the dried materials was cooled to the temperature of liquid oxygen and allowed to abstract the residue of dry air from a vessel which had previously been partially exhausted. The initial and final pressures in the vessel were taken by means of a delicate McLeod gauge. The total internal volume of Lambert's apparatus was 610 c.c., and in each test 10 c.c. of the adsorbent, in the granular state, was used. The following table, which is derived from a more complete table in the Oxygen Committee's Report, gives the relation between the initial and final pressures in Lambert's apparatus when the former assumed values *circa* 0·1, 1·0, and 10 mm. respectively:—

* H. BRIGGS, "Prehensility: a Factor of Gaseous Adsorption," *Proc. Roy. Soc. Edin.*, 1922, 42, 26

Digitized by Google

Reduction of Pressure: *volume of adsorbent*, 10 *c.c.*; *volume of space evacuated*, 610 *c.c.*; *adsorbent cooled by liquid oxygen.*

Adsorbent.	Initial Pressure P mm.	Final Pressure p mm.	Pressure Reduction Factor $f = \frac{P}{p}$.
British palm nut charcoal	circa 0·0575	0·000005	11,500
German impregnated charcoal	0·1 0·147	0·000005	29,400
Silica gel (American)	mm. 0·109	0·00003	3,630
British palm nut charcoal	circa 2·585	0·00025	10,340
German impregnated charcoal	1·0 1·22	0·0002	6,100
Silica gel (American)	mm. 1·17	0·00015	7,800
British palm nut charcoal	circa 11·34	0·0008	14,175
German impregnated charcoal	10 12·05	0·003	4,017
Silica gel (American)	mm. 12·1	0·004	3,025

Other experiments* on higher initial pressures proved that, volume for volume, the plumstone charcoal made during the war by the British Anti-Gas Department was preferable, for the production of high vacua, to any other then available (1920). At the same time it was shown that even the best silica—and one considerably more active than the American variety was prepared—was very inferior to a good charcoal in evacuating power; silica, moreover, does not act so rapidly as charcoal in absorbing gas at low concentration, and should there be any hydrogen in the envelope of the flask, virtually none of it can be taken up by silica; an activated charcoal, on the other hand, exhibits, at —190° C., a good deal of physical affinity for hydrogen.†

While colloidal silica may be of use for small Dewar vessels intended to last a comparatively short time, it cannot be recommended for containers which are expected to give satisfactory service, without the need for re-evacuation, for a few years.

A metal container of 50 lbs. capacity has a vacuous envelope of 6·27 litres, and is generally provided with about 200 grams of cocoanut charcoal or the same volume of some other charcoal.

The volume of the charcoal is about 0·46 litre; the relation between the volume evacuated and that of the adsorbent is, therefore, 13·6 : 1. The equivalent relation in Lambert's apparatus was 61 : 1, or 4·5 times that for the container. If we may assume the pressure-reduction factor to be directly as the amount of adsorbent used, that factor for the container will thus be 4·5 times any one of those of the above table, depending upon the kind of absorbent employed. With a usual charge of British palmnut charcoal, for example, an initial pressure of 0·1 mm. in the vacuum space will be reduced by the charcoal to about 0·000002 mm. when the container holds liquid air. At that final pressure the transference of heat across the vacuous envelope by conduction is negligible. Even if the initial pressure is as high as 1 mm., the final pressure will only be about 0·00002 mm., and, again, the conduction loss will be of little account in comparison with the loss due to radiation.

Given that these metal flasks contain a sufficient weight of dry charcoal, then, it is unnecessary, in the preliminary exhaustion by pumping, to reduce the pressure in the envelope to the very low value required with the glass flask; the charcoal can be depended on to transform a coarse into a fine vacuum.

Drying of Charcoal.—No charcoal should be used for a Dewar vessel without first being thoroughly dried, because dampness greatly extends the time of the evacuation; it also reduces the prehensility of the charcoal. Once the dry charcoal is introduced, the flask should be sealed up with the least possible delay, as these charcoals absorb water from the air with more avidity than calcium chloride, and eventually take up, at room temperature, about one-quarter of their weight of moisture.

* *Ibid.*

† H. H. Sheldon, *Phys. Rev.*, 1920, **16**, 170, by subjecting it to a temperature of 1,000 deg. C. for 3½ hours in vacuo, has been able to prepare a charcoal which is actually able to absorb more hydrogen than nitrogen. It does not follow that that ratio will be the same at the very low pressure at which adsorption takes place in a vacuum bottle; but if it ever becomes desirable to make flasks of steel—a metal containing appreciable amounts of hydrogen—Sheldon's process would become worthy of careful study.

Digitized by Google

An entirely erroneous impression has grown that, in drying, care must be taken not to overheat the charcoal, or its activation will be injured. Actually, the only risk of overheating is that the material may go on fire. If a small furnace of the reverberatory type be available, giving a reducing atmosphere, the charcoal may be dried by heating in thin layers at about 600° C. for two or three hours. If the drying has to be done in a muffle, the charcoal should be spread out *in thin layers* on metal trays, and be kept at 300°—400° C. for four hours; it should be stirred from time to time. This final heating, instead of spoiling the activation, has always, in our observations, slightly improved it. Even after these processes the charcoal will retain a little moisture—usually from ¼ to ½ per cent. Heating for a long time at 1,000° C. does not dispel every trace. It will thus be realised that any attempt at drying at 100°—150° C. at atmospheric pressure, even when prolonged over several hours, will be ineffectual.

We have made use, for small flasks, of a variant upon the construction illustrated by Fig. 10 which has the advantage of preventing, more completely than hitherto, the charcoal adsorbing moisture. We see no reason against its adoption for large vessels. The method is shown by Fig. 17, which is a vertical section of a portion of the lower half of the vessel. *A* is the outer and *B* the inner globe; *C* is a straight, solid-drawn copper tube. The

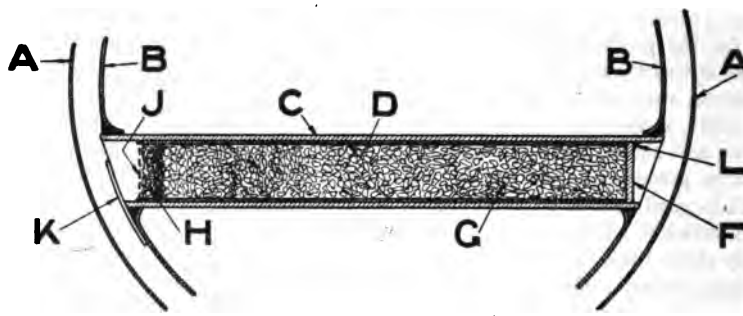


FIG. 17.—Use of Charcoal in Tubular Cartridge.

figure indicates the manner of bending in the metal of the hemisphere *B* round the end of the tube *C*, so as to form pockets for the solder. The charcoal *G* is held in an inner tube *D*, of thin brass, which tube is a sliding fit in *C*. *D* is closed at one end by the disc *F*. The charcoal tube is prepared and sealed, independently of the rest of the flask, in the following way:—The charcoal is dried in the manner above described. Immediately upon its removal from the furnace it is dropped into the tube *D*; it is well shaken down (it may be forced into place by pressure); the mouth of the tube is connected to a sulphuric acid bubbler so that, on cooling, the charcoal can take in nothing but dry air. When the charcoal is cool and bubbling has ceased the tube is disconnected from the drier; the loose plug *H*, of calcined asbestos wool, is inserted, and a disc of coarse brass gauze, *J*, soldered across the mouth. The gauze is then quickly smeared over with molten Wood's metal, which readily adheres to clean brass, and which thus seals the tube. Wood's metal (Bi 15; Pb 8; Sn 4; Cd 3) melts at 160° F. The tube, thus sealed, may be kept any length of time without deterioration of the charcoal.

When the flask is completed with the exception of the attachment of the lower external hemisphere, the charcoal tube is slipped into place, held by a touch of solder at *L*, and a small guard, *K*, intended to catch the fusible alloy when it melts, is soldered on. On its completion the flask may be subjected to leakage tests, the charcoal still remaining sealed up. When evacuation commences steam is injected into the inside of the bottle, the fusible metal runs off the gauze *J*, and the charcoal is for the first time exposed to the vacuum space; since it is dry, evacuation is a short process.

Decay of Vacua in Metal Flasks.—Every metal vacuum flask, after being in use for a longer or shorter period, requires re-evacuation. It is subject to the entry of air through openings which are so excessively minute that no ordinary test for leakage will reveal them, and eventually—it may be some months or some years after the original evacuation—air has accumulated to such an extent in the envelope that the charcoal is no longer able

Digitized by Google

sufficiently to reduce the pressure when liquid air is poured into the vessel; as a result, a container which at first had an evaporation rate of 3 lbs. of liquid per day will gradually deteriorate until its original rate is doubled—when re-evacuation becomes desirable—or trebled, when re-evacuation becomes imperative.

In order to obtain definite figures as to the rate of decay of the vacua of these flasks, and as to the magnitude of the "initial pressure" under practical conditions, experiments have been made with an apparatus by means of which the outer wall of a vessel could be punctured, the pressure within the envelope measured by a McLeod gauge, and the puncture sealed without damaging the flask or spoiling the vacuum. A good deal of information, recently presented in a paper before the Royal Society of Edinburgh,* was obtained by means of this apparatus. The following summary of the results will suffice for the present.

The most important set of experiments were made on six 3-litre gilding-metal flasks of the design shown in Fig. 10. These were identical in construction, and each contained 10·45 grms. (23 c.c. gross volume) of plumstone charcoal. The volume of the vacuous envelope was 1·163 litres. Puncturing was always performed with the bottle at room temperature, inside and out.

It must be emphasised that all the 3-litre bottles tested were in serviceable condition. Their evaporation rates ranged between 34 grms. of liquid per hour (0·39 litre of gas at 0° C. per minute) and 60 grms. per hour (0·70 litre of gas per minute). With the exception of the first, whose vacuum was 20 months old, the flasks were evacuated 27 months before they were first punctured. The method of evacuation employed by the maker gave a comparatively high degree of vacuum.

Flask No. 1, upon being punctured, was found to have a pressure in the envelope of 0·33 mm. The rate of decay of the vacuum was, therefore, about 0·0165 mm. per month —a rate corresponding, it might be of interest to note, to the ingress to the vacuum of about 270 million molecules of air per second. Thus air-tightness in a vacuum flask is decidedly a relative matter. The bottle—thanks to the charcoal—was, nevertheless, serviceable; its evaporation rate was 55 grms. per hour; normally it would have been allowed to go many months longer before re-evacuation was thought necessary. But for the charcoal, the flask would have become useless in a few weeks after leaving the maker.

Flask No. 2, when punctured, was found to have a pressure in the envelope of 0·418 mm. Decay was at the rate of about 0·015 mm. per month.

Flask No. 3.—envelope-pressure, 0·1975 mm.; rate of decay, about 0·0073 mm. per month.

Flask No. 4.—envelope-pressure, 0·0624 mm.; rate of decay, about 0·0023 mm. per month (unusually low).

Flask No. 5.—envelope-pressure, 0·1785 mm.; rate of decay about 0·0066 mm. per month.

Flask No. 6.—envelope-pressure, 0·4288 mm.; rate of decay about 0·016 mm. per month.

The average rate of decay of the vacuum of these six 3-litre flasks was about 0·011 mm. per month.

A similar examination was made of two Heylandt vaporisers,† built in Germany. It is not known how long previous to puncturing the evacuation was carried out. The first was a 3-litre brass vessel, losing by tranquil unassisted evaporation 51·7 grms. per hour; its vacuum was 0·0717 mm. The other was especially interesting in being the only steel flask examined; it was a 2-litre bottle, of the usual form of construction, all joints being made by soft solder; its unassisted evaporation-rate was 61·4 grms. per hour (high for a flask of this size), and its vacuum 0·018 mm.

We also determined the pressures in the vacuum spaces of three 50-lbs. containers, which were selected for test because their evaporation rates were excessive. The early history of the containers could not be obtained; nor do we know the character and weight of the charcoal they held.

The first container had an evaporation-rate of 6 lbs. 7½ ozs. per 24 hours (128 grms. per hour); the vacuum was 0·135 mm. If we allow for the possibility of the charcoal being

---

* H. Briggs and J. Mallinson, "Further Tests upon Dewar Flasks intended to hold Liquid Air,' *Proc. Roy. Soc. Edin.*, 1923, **43**, 16).

† We are indebted to Messrs. Brown and Mills for lending these vessels and the containers for test.

Digitized by Google

poor in quality and assume a pressure-reduction factor of only 2,000, the charcoal, when it came into action, would reduce the pressure to 0·000068 mm. At that pressure the loss due purely to conduction across the vacuum space would be only 3 grms. per hour. It appeared, therefore, that the high rate of loss was due almost entirely to radiation; that conclusion was verified by re-evacuating to an initial pressure of 0·005 mm., when it was found that the rate of loss was only very slightly reduced.

A second container, losing 9½ lbs. per day (180 grms. per hour) had the remarkably fine initial vacuum of 0·007 mm. It was discovered that the excessive loss was due to the charcoal dish having broken loose.

A third, in which liquid air evaporated at the rate of 6 lbs. per 24 hours (113 grms. per hour) revealed a pressure of 2·9 mm. in the vacuous space.

Conduction of Heat Down the Necks of Containers.—The heat flowing down the metal neck is, with long-necked bottles, altogether, or nearly altogether, received by the cold gas flowing in a continuous stream up the tube, and none, or very little, enters the liquid from that source. Even with a vessel having a short, wide neck, like that of Fig. 10, the ingress of heat to the liquid *via* the neck (the *neck-loss*, as it may conveniently be expressed) is little more than a quarter the total ingress.

The question was investigated by means of temperature measurements taken at a number of points in the necks of four containers in use at the Newcastle mine rescue station.

The conclusions were further put to the test by making 12 special containers with necks which were shorter and thicker than those commonly adopted for such vessels. Ten of these containers proved to be sound, and their evaporation rates proved to be little, if any, greater than those of vessels of the type of Fig. 8. A complete account of these experiments has been published.* The results indicate that container necks may be shortened with advantage. What is to be taken as the minimum permissible length for any given section of tube must be left for the further experiments now being carried out for the Oxygen Research Committee to determine. It is, however, possible to suggest that a neck of solid-drawn German-silver tube, of 21 S.W.G. (0·032 in.; 0·8 mm.), ½ in. bore, and of a length of 7½ ins., of which 5 to 5½ ins. is surrounded by vacuum, would be found serviceable. Shorter though it is, the conductivity of that tube is considerably less than that of the necks of the ten special vessels just referred to; its adoption would bring about a reduction of about 5 ins. in the ordinary height of a container. With a short neck, the use of asbestos pads (p. 15), or of an equivalent device to limit the movement of the inner globe, becomes essential.

Such an alteration in construction would strengthen the flask and slightly reduce the weight, while underground transport (an object we have especially in view) would be facilitated by the reduced height.

Losses by Evaporation due to Radiation and Conduction Across the Vacuum.†—As was stated in the introductory sentences of this Part, the chief sources of heat-transfer to a vacuum flask holding liquid air are radiation and conduction across the vacuum space, and of these the first is, for a good flask, by far the more important. It is, indeed, only when the vacuum has been considerably impaired that the conduction-loss reaches a magnitude commensurable with that of radiation.

Dr. Briggs devised a method of quantitatively determining their losses in any given flask,‡ and illustrated it by experiments upon a glass flask and upon one of the 3-litre "vaporisers," Fig. 10. For the latter he also ascertained the loss by conduction down the neck-tube (cupro-nickel; 3½ ins. long; 2⅜ ins. surrounded by vacuum; ⅝ in. bore; metal, 0·024 in. thick), which loss—the neck being unusually short and wide—was by no means negligible. The method of experiment was to ascertain the total loss when the outside of the bottle was kept for periods ranging between 9½ and 21 hours at a series of constant temperatures between 10° C. and 100° C. The results enabled equations to be written whose solutions yielded the desired information.

---

* H. Briggs, "Experimental Analysis of the Losses by Evaporation of Liquid Air contained in Vacuum Flasks," *Proc. Roy. Soc. Edin.*, 1921, **41**, 97.

† In preparing this Section use was made of physical constants and formulæ collected by the late Dr. J. A. Harker, F.R.S., and his co-workers. They are included in the report of the Oxygen Research Committee, where a complete account and valuable criticism of this method of analysing the evaporative loss of a vacuum vessel will be found.

‡ *Proc. Roy. Soc. Edin.*, 1921, **41**, 97.

Digitized by Google

The results for the 3-litre metal flask were :—

Analysis of Evaporative Loss of 3-litre Flask at Four External Temperatures.

External Temperature.	Neck-loss.	Conduction Loss.	Radiation Loss.	Total Loss.
Degrees C.	Grms. per hour.	Grms. per hour.	Grms. per hour.	Grms. per hour.
10	11·0	7·7	23·2	42·5
44	15·4	9·4	36·6	61·5
70	15·2	10·8	50·2	72·0
100	14·6	12·4	70·6	97·6

At an ordinary external temperature of 15° C, the loss by radiation would thus be thrice that due to conduction across the vacuum space. Had the reflecting surfaces been polished to the highest possible degree, the radiation loss would have been only about one-third of its actual value.

Let us now consider a 50-lb. container having a long, thin neck like that of Fig. 7. As has been shown, the neck loss of such a vessel is negligible. The best copper container of this size regarding which we have direct information had an evaporation rate of 2½ lbs. per 24 hours (47·2 grms. per hour) shortly after evacuation. The pressure in the envelope having been reduced by pumping to less than one-thousandth of a millimetre, the charcoal would, at liquid air temperature, bring the pressure down so far that the loss by conduction across the vacuum would also be negligible. Hence, virtually the whole of the stated evaporation loss was due to radiation. Had the polished copper surfaces been in the best possible condition, the radiation loss would have been only 24·4 grms. per hour; hence, even in this favourable instance, radiation was nearly twice the lowest possible.

An analysis of the case presented by the first of the three containers, referred to on p. 21, shows radiation to have been 2·8 times the least possible for brass, the metal of that flask.

Brass tarnishes less readily than copper. Despite the last example, the bulk of the evidence points to the German brass flasks as having reflecting surfaces more nearly approaching the perfect than our copper ones, so that, though a copper surface at its best has rather more than one-half the emissivity of a brass surface at its best, the actual brass surface in a vacuum vessel may have an emissivity as low as, or even lower than, that of an actual copper surface.

There is clear need of more attention to this highly-important question of the polish of the reflecting surfaces. The tendency is to expend too much care on fine evacuation and too little on polishing and retaining the polish. The flask should be completed as soon as possible after polishing the hemispheres. As little time as possible should elapse between completing a flask and evacuating it. Unless evacuation can be performed at once, it is advisable to swill out the envelope with nitrogen, then temporarily closing the lead tube; this prevents oxidation of the bright surfaces and keeps the charcoal dry. Testing for air-tightness should never be made by forcing air under pressure into the envelope; nitrogen should be used instead.

A container ought not to be permitted to deteriorate far before it is re-evacuated, especially if it be allowed to stand empty. The envelope of an empty vessel in second-rate condition may contain air at an "initial" pressure of several millimetres. Low though that pressure may be, we have observed it to cause oxidation of the surfaces in course of time, with the result that, after re-evacuation, such a vessel will have a higher evaporation rate than is desirable.

Evacuation of Dewar Flasks.—From the practical point of view the main interest of the section on the decay of the vacuum is that it shows the needlessness of excessively fine exhaustion of the envelope of a vessel in which charcoal is used. The experiments on 3-litre vessels make it clear that, even were it possible to exhaust the space totally before sealing-off, the pressure in it in a month's time would be, on the average, 0·01 mm. when the bottle was at normal temperature inside and out. It has also been observed that metal flasks with satisfactory evaporation rates have envelopes in which the pressure, when the bottle is at normal temperature, inside and out, is a third or half a millimetre.

In certain instances British plants intended to evacuate metal flasks have been designed to bring the pressure down to less than 0·001 mm., while some actually include large

Digitized by Google

charcoal bulbs sealed to the evacuating system, which bulbs, when cooled by liquid air, are intended to convert a pressure, already reduced to a low value by pumping, into one very much lower still. Fine evacuation plant of this description is necessary in connection with glass or porcelain vacuum vessels, or in exhausting the bulbs of incandescent electric lights; to adopt it for Dewar metal flasks, however, is not only to incur unnecessary initial expenditure; it reduces the output of the plant and increases the cost of the vessels treated.

Re-evacuation has been carried out for several years at certain English rescue stations; simple plant—usually a hand-driven Geryk pump, and in one instance a rougher pump still—is used, and the operation, judging by the evaporation rates of the vessels, is satisfactory.

According to Banneitz, Rhein and Kurze,* Messrs. Ahrendt, the largest makers of Dewar vessels in Germany, find it sufficient to evacuate the envelope roughly by means of an oil pump.

The matter was tested further in making the ten special containers to which we have referred on p. 22. Six of these were evacuated below 0·001 mm. The other four were pumped out roughly, using a simple upright mercury manometer as gauge; the pressure obtained would certainly not be less than 0·1 mm. and may have been as high as 0·5 mm. The average evaporation rate of the six was 3 lbs. 10 ozs., and of the four 3 lbs. 8 ozs. per day. The flask with the lowest rate was one of the four. With the exception of the difference in degree of evacuation, the vessels were identical.

It might be argued that excessively fine evacuation is admissible because the flask will then last longer before re-evacuation becomes necessary. The answer is, first, that when the increase in time and cost involved is compared with the increase in life, the advantage claimed is found to be not worth while, and, secondly, that the additional life may be secured much more cheaply by using a little extra charcoal.

Evacuation to a finer vacuum than 0·05 mm. is unnecessary. If the charcoal is dry, the operation is simple and speedy. The flask is raised to a temperature not exceeding 100° C. by being placed in a steam oven and by having a steam jet blowing off inside. A single-cylinder oil pump is suitable, and connections may be made by stout rubber pressure tubing, wired on. When the desired pressure has been obtained the lead tube is sealed in the manner described (p. 14).

---

* *Ann. der Phys.*, 61, Scr. IV.

Digitized by Google

PART III

MISCELLANEOUS.

Compressed Oxygen Reviving Apparatus.—The revivers at mine rescue stations are principally of the simple type, consisting of an oxygen cylinder, a reducing valve, a throttle, a distensible bag and a face-mask connected to the bag by a length of flexible tubing. Other forms are the Pulmotor, Bratt's apparatus, and the Lungmotor, all of which aim at producing alternate inflation and deflation of the lungs by artificial means. The Pulmotor is chiefly remarkable for its liability to get out of order; it is the *bête noir* of rescue station superintendents. Bratt's apparatus and the Lungmotor are rather simpler devices in which the rate of forced breathing is directly controlled by hand instead of being mechanically controlled as in the Pulmotor.

We have tried all these devices; in addition to the drawbacks of complexity, bulk and weight, those producing forced breathing are physiologically unsound, and their use is not free from serious danger. Forcibly to blow oxygen into lungs which are already distended to the full, or to apply strong suction to lungs already deflated, is to risk permanent injury to those organs. Again, though one tries to reduce the possibility by drawing the tongue well forward, there is a chance of these apparatus functioning upon the stomach instead of on the lungs. We therefore consider that all forms of forced-breathing revivers should be abandoned, and that the simple form, in conjunction with artificial respiration, should be employed solely.

A defect of some existing simple revivers is the small size of the cylinder. In one instance the volume was ascertained to be 130 litres when charged to 120 atmos.; if the oxygen were being delivered at the rate of 7½ litres per minute—and a less rate is seldom practicable, as the apparatus is a non-regenerator—the cylinder would last only about 17 minutes. In the extreme case 12 litres per minute may need to be fed, and then the cylinder would be exhausted in 11 minutes. The cylinder of the Pulmotor is larger, the volume, expanded from 120 atmos., being 264 litres. It is true that a spare cylinder may be carried with any type of reviver; but in any case it would be preferable to equip the appliance with a cylinder capable of holding as much as that of a rescue apparatus, namely, 280 or 290 litres. It would be convenient if the same kind of cylinder were used in both rescue and reviving apparatus.

The tube between the bag and the face-mask often has too great a resistance. An undue resistance at this point may defeat the purpose of the appliance. This tube should be made shorter and wider than is common. The outlet valve from the mask, again, should not be too small; a Rosling valve (Second Report, p. 31) is a suitable and simple form.

A reviving apparatus may be needed either in foul or fresh air. In the former it must be able to supply the whole of the lungs' requirements; in the latter, however, it is more economical and quite as serviceable to supply, say, 2 litres of oxygen per minute to the patient, providing that there are the means of enabling him to make up the volume to 7 or 8 litres per minute (an average lung ventilation) by drawing in outside air. Fig. 18

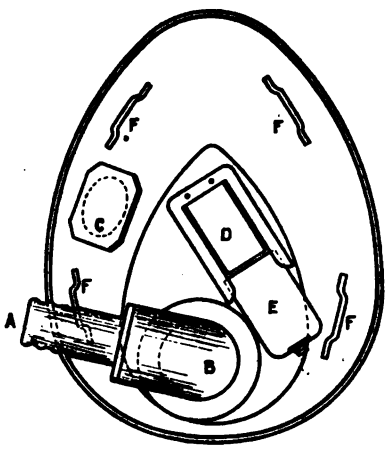


FIG. 18.—Face-mask for Reviving Apparatus.

Digitized by Google

is the front view of a face-piece designed by Dr. Haldane for administering oxygen to gas-patients during the War, and now modified to permit of its use in either foul or fresh air. The oxygen inlet tube is at *A*. Inside the joint-box *B* there is a valve, which closes during exhalation. *C* is a Rosling exhaust valve; *D* is a thin rubber flap, held at one edge, and equally free to swing into or out of the mask; *E* is a close-fitting metal slide (shown in the off position), by means of which it is possible to close the opening in which *D* is set. When the appliance is being used in poisonous air the slide is closed and expiration takes place through *C*. When in use in fresh air the slide is left open, and the oxygen supply cut down to about 2 litres per minute. The flap imposes a very slight resistance to indrawn air—a resistance sufficient to ensure that the oxygen from the supply pipe is inhaled first and is drawn to the bottom of the lungs; then the flap moves aside to allow fresh air to pass, and so the lungs are able to fill themselves.

The mask is held in position by elastic bands passing from the loops *F* round the patient's head. It will be observed that the inlet tube *A* is turned to one side; this is to facilitate the administration of oxygen during artificial respiration by Schafer's method, when the patient is lying face downwards. A regular practice is made of turning the head so that the left side is underneath. During use the reviver stands on the right-hand side of the operator.

The throttle, attached immediately after the reducing valve, should permit of the rate of flow being adjusted from 1 to 12 litres per minute. A flow-gauge would be a useful auxiliary to a reviver, especially when the appliance is used to give oxygen in fresh air.

It has recently been shown by Professor Yandell Henderson and Dr. Howard Haggard* that, after serious gassing with carbon monoxide, the breathing is so much diminished (as the result of excessive washing out of carbonic acid from the body and other causes) that oxygen alone is comparatively ineffective in removing carbon monoxide from the blood and promoting recovery. They therefore introduced the plan of using oxygen mixed with about 5 per cent. of carbonic acid. In experiments on animals it was found that this mixture was very greatly more effective than pure oxygen in promoting recovery. Owing to the free use of carburetted water-gas for lighting purposes in American towns, there are many cases of carbon monoxide poisoning. To deal with this situation special emergency cars with trained crews have been organised in New York. In the Borough of Manhattan, City of New York, the Gas Company keeps five such cars, each with three crews on duty in successive shifts, so that a car is at once available at any hour. This organisation made it possible to test on a sufficiently large scale the use of the new mixture for reviving purposes, and the results were very favourable.

There seems to be no doubt that, wherever the method is practicable, far better results will be obtained if 5 per cent. of carbonic acid is present in the oxygen used for reviving. Unfortunately, however, the quantity of gas needed is large, so that a larger cylinder is required. This will, we fear, militate against the general use of the new method for underground emergencies; but it can be applied under some conditions. Henderson and Haggard describe an apparatus for the purpose.

Liquid Oxygen Reviving Apparatus.—Though the appliances now to be described have not yet been used for resuscitation purposes in mines, we think it advisable to deal with them, having in view the fact that, at stations where liquid air is employed for rescue apparatus, revivers which are also supplied with liquid air or liquid oxygen might at some future period be preferred.

Though other forms of liquid oxygen vaporisers were known before, Sir James Dewar was, we believe, the first to devise a *conduction* vaporiser—of which Griffiths' is the latest form—a type in which the evaporation of the liquid in a vacuum flask is stimulated by admitting a controllable amount of heat from the outer atmosphere. He also introduced the *electric* vaporiser, in which a resistance coil is inserted into the liquid through the neck of the flask. By varying the current passing through the coil, the gaseous discharge can be adjusted readily and accurately. Though valuable for certain other purposes, the electric form is, however, less serviceable for mine rescue purposes than the two here described.

---

* Report to the American Gas Association of the Commission on Resuscitation from Carbon Monoxide Asphyxia." *American Gas Association Monthly*, September, 1922.

Digitized by Google

Yet a third principle is that of the Heylandt vaporiser (Fig. 19),* where liquid air is forced from the vacuum flask into an external boiler, in which it volatilises. In the figure, *A* is the vacuum flask, and *D* a tube leading into the sheet-metal boiler, *E*, which is provided with a number of hollow finger-like projections, *H*, serving as heat-catchers.

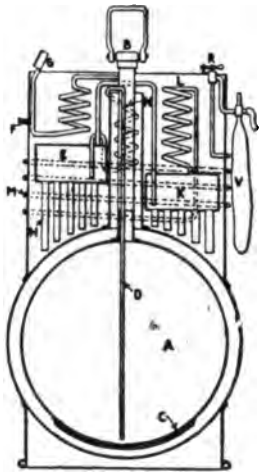


FIG. 19.—Heylandt Vaporiser.

The bottle is filled through the neck, *B*, which is then closed by a screw stopper provided with a carrying handle. Evaporation of liquid in a flask (stimulated at first by turning the bottle upside down) produces an increase of pressure in the bottle. The pressure is registered by the gauge *G*. There is a relief-valve *F*, which is adjusted to discharge at about 12 or 15 lbs. per sq. in.

Gas produced in *E* by the evaporation of liquid syphoning over is conducted into a second boiler, *K*, whose function is to catch and evaporate any liquid which may be carried across with the gas; then the gas passes through warming coils, *L* and *M*, to a throttle-regulator, *R*, and thence to a distensible bag, *V*, and to the tube leading to the patient's face-mask. The flow is controlled by *R*. When that valve is nearly closed, pressure in the boilers, *E* and *K*, increases, and the discharge of liquid by the syphon tube, against that pressure, is less rapid. When *R* is opened at full, the back-pressure in the boilers is relieved and the liquid passes over quickly; when the regulator is completely closed, the only gas discharging is that due to normal evaporation in the bottle—a flow usually amounting to ½ or ¾ litre per minute.

The Heylandt vaporiser has the advantage of not fractionating the oxygen-nitrogen mixture; that is to say, if the bottle contains a liquid mixture of 80 per cent. oxygen and 20 per cent. nitrogen, the gas discharged by the vaporiser has also that composition. It is, in fact, the only known form for which that merit may be claimed, and thus the only kind that can be adopted if the liquid contains a relatively large amount (20 to 40 per cent.) of nitrogen. The flow from this vaporiser can be regulated with ease and certainty over a range sufficient for resuscitating purposes.

Mr. E. A. Griffiths' vaporiser is shown in Fig. 20.* It consists of a copper vacuum vessel with interior charcoal tube, *F*, the inner sphere being packed with asbestos wool, *E*, which absorbs the charge of liquid and prevents spilling. The base of the bottle is formed of an aneroid diaphragm, *A*; to the diaphragm is attached, on the inner side, a disc of copper, *B*. The figure shows the position in which there is a gap between the disc, *B*, and the inner vessel; in that position the only gas emitted is due to normal or unassisted evaporation within the flask. There is a small hand-wheel, *D*, by means of which the diaphragm may be flexed in and the disc brought against the inner bottle. More or less pressure can be exerted between the two, and the heat-conductivity of the bridge across the vacuum space thereby altered. To increase the range, we carried out a variant upon the design.

* *Coal Age*, 1922, 21, 655.

Digitized by Google

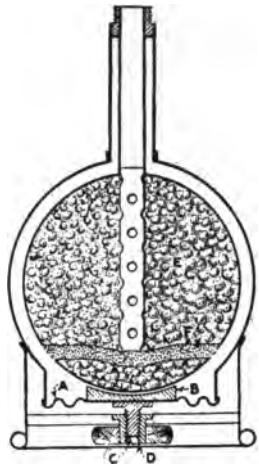


FIG. 20.—Griffiths Vaporiser.

illustrated; in this, the greater part of the lower outer hemisphere was replaced by a copper shell having circular corrugations; the contact piece, *B*, was also enlarged. The corrugated shell took the place of the German-silver diaphragm, and was a more effective heat-catcher. In this way rates of flow anywhere from 15 to 0·6 litres per minute were obtainable.

Griffiths' appliance is simple, compact, self-contained and readily understood by the non-scientific operator. As already stated (p. 4), it was originally intended as the means of supplying oxygen to a rescue apparatus, but probably it will find a wider field of utility as a reviver and in hospitals. As the appliance fractionates a nitrogen-oxygen mixture, causing much of the nitrogen to be volatilised first, it is not suitable for the liquid "air" now made at our rescue stations; it should, indeed, be charged with liquid containing over 95 per cent. of oxygen.

At the temperatures we find in British mines no difficulty is to be anticipated in sufficiently warming the air feeding from a vaporiser to a breathing mask. Convolutions of copper tubing, as in Heylandt's form, may, of course, be used, but we think a simpler and better way is to allow the gas to pass through a 15-ft. length of ordinary rubber bunsen tubing fitted between the vaporiser and the bag. We have often used a 12-ft. piece in this way, and have never had any trouble on the score of excessive cold. Mr. Griffiths passes the oxygen through four narrow metal coils encircling the neck of the flask before letting it enter the flexible tube.

The Process of Absorption of Carbon-dioxide by Solid Caustic Soda.—As was stated in the Introduction, Dr. E. Gilchrist was given permission to publish an account of a series of experiments on the manner of absorption of CO_2 by caustic soda which she and Mr. D. Penman made while acting as assistants to Dr. Briggs. A full description of the apparatus and experimental method will be found in Dr. Gilchrist's paper.* It is sufficient here to say that the soda granules rested on gauze trays held in a metal case, so as to reproduce, as nearly as possible, the conditions obtaining in the purifier of a rescue apparatus. Arrangements were made whereby air containing 4 per cent. of CO_2 (representing expired air) could be circulated over the granules, and could be cooled, heated, dried or saturated with moisture at any desired temperature. The experiments allowed of the following conclusions being reached, which are not without importance to the designer of mine rescue apparatus:—

(1) Too much or too little moisture in the air to be purified is detrimental. The best results were obtained when the proportion of moisture was approximately that carried by air saturated at temperatures between 60° C. and 90° C.

* *Proc. Roy. Soc. Edin.*, 1921, **41**, 128.

Digitized by Google

(2) The best results for absorption were obtained when the canister was kept at a temperature of 60° C. to 100° C. Below and above these temperatures the absorption efficiency fell off rapidly. Below 10° C. and above 100° C. the efficiency was extremely poor.

(3) It is advisable to take measures to secure good heat conduction within a receptacle in which this chemical action is going on, so as to preserve, as nearly as possible, an even temperature in all parts. Otherwise at some parts the action may become violent, with consequent excessive rise of temperature and stoppage of the reaction, while at others, especially near the entrance opening, the temperature may never rise sufficiently high to give good results.

(4) The particles should be of a size and shape to give a fair surface of exposure for absorption. Excessively large pieces or sticks are for this reason to be avoided. Provided the conditions as to moisture and temperature are at their optima, however, there is no need to decrease the size of particle unduly in order to increase the surface. For example, given such conditions, granules 6 or 7 mm. in diameter will, by the swelling action described below, be entirely or almost entirely used up.

(5) The particles must be so spaced as to give sufficient room for swelling. There should be a greater volume of insterstitial space in a canister than of actual solid caustic soda. A disregard of this requirement leads to the coalescence of the granules by swelling, and to the blocking of the air passages. This, in turn, may involve a greatly increased resistance, which is highly detrimental in rescue apparatus and which, at the same time, decreases the availability of the caustic to the CO_2.

(6) In the circumstances giving the best absorption the caustic particles were always found to have swollen, sometimes to three times their original linear dimensions, and in many cases were found to be hollow inside. A granule begins its active life by taking up a considerable amount of moisture, and attains a plastic state. The action of CO_2 on such a body is to coat it with a layer of spongy, dry carbonate. The next effect is a penetration, by capillary attraction, of the soft caustic through the skin of spongy carbonate, and a further attack by the CO_2 on the soda thus brought within its reach. The continuance of the action leads to the formation of a carbonate shell with a hollow interior, and to a great increase in the apparent bulk of the particle. When absorption is at its best, this action continues until there is no caustic soda left behind; in other cases until only a small granule of soda is left, apparently lying detached in a larger shell of sodium carbonate.

Training in Carrying Out Leakage Tests.—We consider that rescue men should be instructed, as an essential part of their training, in the method of making the water immersion test for leakage. At one station with which we are acquainted the test is carried out as a part of the routine at every meeting during training and at the subsequent quarterly practices. The following is the system adopted at the station in question:—

The apparatus are laid out or hung up ready, with the covers of the relief valves—if such covers are required—screwed on.

Each member of the brigade removes from his apparatus the belts, straps and covers which are not to be immersed and hangs them up or lays them aside.

The captain then stands at one side of the portable water-bath, which should be large enough to immerse all parts of an apparatus at once; the other members, each carrying his apparatus, line up in Indian file, facing one end of the bath; the instructor or his assistant stands at the other end.

The men pass the bath, one by one, at the side opposite the captain, each, with the help of the captain, testing his apparatus by immersion.

When at the tank, a man plugs the rubber mouthpiece orifice with his thumb (not by a stopper thrust into the metal orifice); the captain turns on the oxygen, notes the gauge, fills the bag by means of the by-pass, exercises a slight pressure on the bag by the hand, and then, but not until then, immerses the apparatus. The immersion should not be deep, but just enough to cover all parts.

If a leak is seen, the instructor tells the man how to proceed to remedy it; if rectification

Digitized by Google

is not easy, another apparatus is substituted for the faulty one. After a leak has been attended to the apparatus is again dipped.

When an apparatus is observed to be tight, the man wipes it with a cloth, refits the covers, straps, etc., and puts the apparatus on.

With the help of the instructor, the captain, last of all, tests his own apparatus.

The pack of the present-day liquid-air apparatus cannot be dipped. The above routine has, with that apparatus, to be modified: the pack has to be disconnected and the bag inflated for the test by means of a hand-pump attached at the uncoupled joint.

It is probably unnecessary to remark at this stage that every rescue man should be practised in the suction test. Though inadequate alone, the suction test is a valuable auxiliary to the water test. It is desirable to apply it, for example, at an inbye fresh air base immediately before commencing any spell of work.

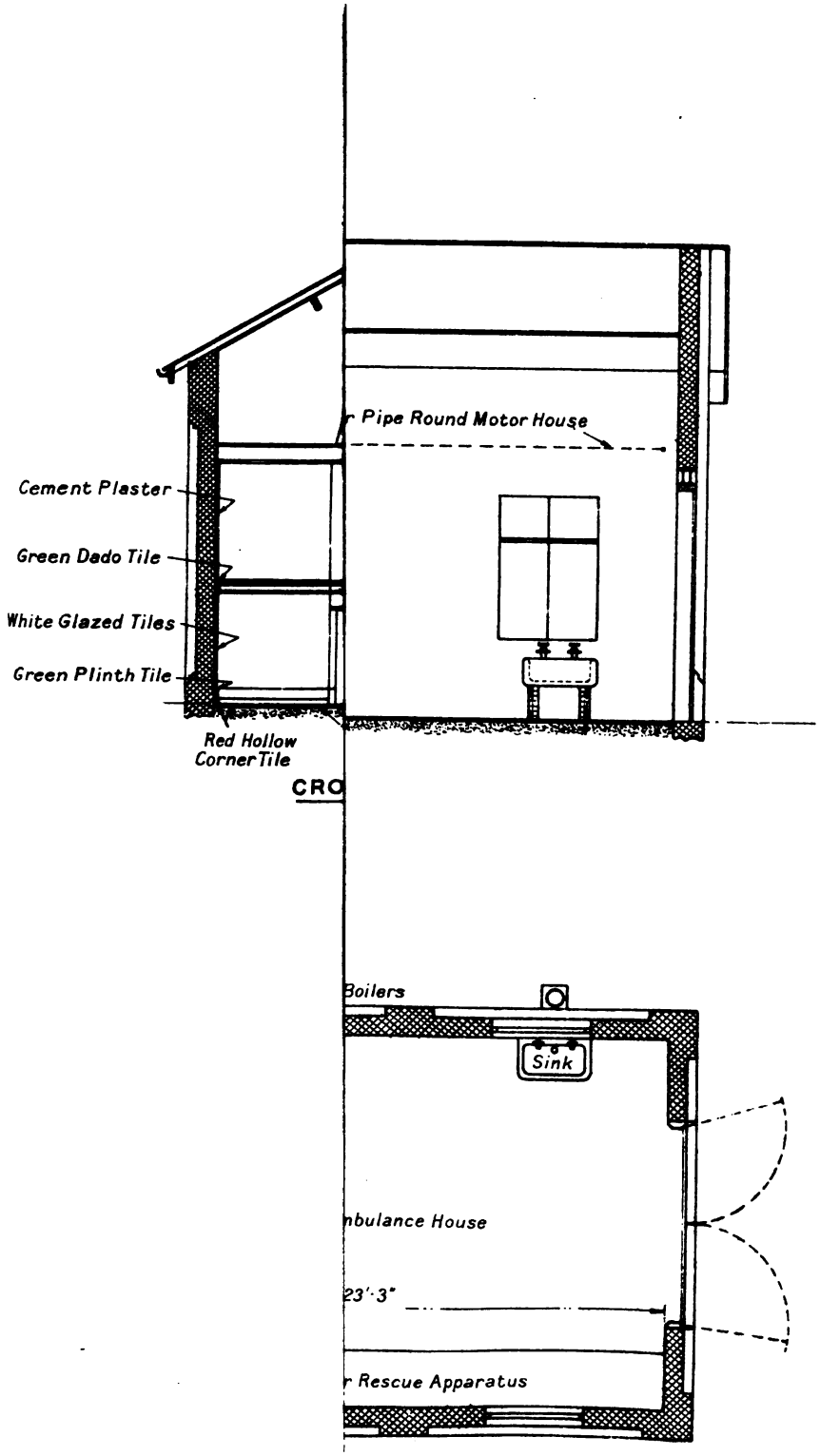
Leakage Test for Equalizer.—In our Second Report, p. 39, we described two forms of equalizer designed to enable a man to perform muscular work while drawing air through a flexible hose. These appliances have been in constant use for several years in at least two rescue stations, where they are found preferable to the smoke-helmet and they have now received official approval. Their advantages are such that we think it likely that they will slowly replace the smoke-helmet entirely. They have, however, one drawback, namely, during use there is negative pressure throughout the appliance. The amount of negative pressure is small in the pipe itself, but during a hard inspiration it is serious enough, at and near the mouthpiece, to make it essential that the apparatus should undergo a monthly leakage test. It is advisable that a written record of such tests should be kept at the station or mine.

The only method of test which at one and the same time detects the fact of leakage, indicates the magnitude, and shows the position of the leak is water-immersion. As the tube and the remainder of the appliance are usually carried separately, they may be tested separately, providing due care is used afterwards in making the joint between them. A simple way of testing the equalizer and mouthpiece is to inflate the tubes and bag (if any) by the lungs, the thumb being kept over the mouthpiece orifice, and then to dip them in the bath. The hose is conveniently tested by attaching a smoke helmet bellows to one end, plugging the other, and then exercising air pressure when the whole tube is lying in water. The coils should be moved about in the water during the test.

Ambulance Rooms.—We are glad to be able to publish drawings (Fig. 21) of the Red Cross room and motor-house at the Brodsworth Main Colliery, near Doncaster, constructed in compliance with a regulation based upon a recommendation of our First Report. Most of the admirable features of the room are clear from the drawing. A good point is the isolation of the room; it is not built on to other sheds in which machinery may be working. It is clear that the comfort of the injured as well as of the rescue brigades has been carefully studied.

Purity of Oxygen in Cylinders which have been Hydraulically Tested.—As more than one superintendent has realised, there is especial need to be on guard against impure oxygen when a storage cylinder returns to the station after having been annealed and hydraulically tested. There is no guarantee that the cylinder was washed-out with oxygen after the water was emptied from it and before it was charged with oxygen. If that precaution was not taken, there will be an additional 0·66 per cent. of nitrogen in the oxygen as supplied, owing to air having filled the cylinder at atmospheric pressure.

Digitized by Google



UNIV. OF MICH.

1850.113578- 753.750.8-24.

Malby & Sons, Lith.

Digitized by Google

Digitized by Google

INDEX

	PAGE.
Absorption of carbon dioxide by Caustic Soda	28
Adsorption—of gas by Charcoal	11, 18
—of hydrogen	19
Ahrendt, Messrs.	24
Air Ministry—Research Department	15
Ambulance rooms	30
Blackett aerophor	4
Bratt's apparatus	25
Brierley rescue station	2, 7
—apparatus	7
Briggs, Prof. Henry	1, 4, 8, 9, 18, 21, 22
Brodsworth Main Colliery—ambulance room at	30
Brown, G. L.	4, 9
Brown and Mills rescue apparatus	4, 10
Carbon dioxide—absorption of—by caustic soda	28
monoxide—gassing by	26
Caustic soda—absorption of CO_2 by	28
Charcoal—adsorption of gas by	11, 18
—drying of	19
—for containers	11
—methods of holding	16i 20
—nature of	17
—prehensility of	12
Claude rescue apparatus	3
Colliery Guardian	4, 6, 9
Colloidal silica	17, 19
Conduction of heat—across vacuum	11, 22
—down necks of containers	22
Construction of containers	11, 12, 15
Containers—liquid air—construction of	11, 12, 15
—decay of vacua of	20
—explosions in	17
—one per brigade	10
Cost of liquid air	2
Decay of vacua in Metal Flasks	20
Dewar, Sir James	11, 26
—flask	11, 20
—evacuation of	23
Drying of charcoal	19
Elliston, E. C.	6
Equalizer—leakage test for	30
Evacuation of Dewar flasks	23
Evaporation—due to neck of flasks	12, 22
—in containers	15
—rate of—from packs	5
Explosions in containers	17
Face-mask for Reviving Apparatus	25
First Report, Mine Rescue Apparatus Research Committee	4, 30
Future possibilities of Liquid Air	3
Gilchrist, Dr. Elizabeth	1, 28
Gilding metal	12
Glass vacuum flasks	12
Griffiths liquid oxygen rescue apparatus	4
—vaporiser	22
Guest & Chrimes, Messrs.	6
Haggard, Dr. H.	26
Haldane, Prof. J. S.	1, 8, 26
Harker, Dr. J. A.	22
Henderson, Prof. Yandell	26
Heriot's Trust—Governors of	1
Heriot Watt College	1
Heylandt liquid air plant	2
—vaporiser	21, 27
Hydrogen—adsorption of	19
Lambert, Major	18
Leakage tests—for equalizer	30
—of liquid air rescue apparatus	8
—training in	29
Liquefaction temperatures	2
Liquid air—composition of	2
—cost of	2
—future possibilities of	3
—plant	2, 7
—reserve of—at rescue stations	7
—transport of	9
Liquid Air and Rescue Syndicate	2
Liquid air rescue apparatus	2
—advantages of	7
approval of	8
testing of	8
Liquid nitrogen	2
Liquid oxygen	2
—rescue apparatus	3
—reviving apparatus	26
Lungmotor	25
Mallinson, John	1, 21
Mansfield rescue station	2, 7, 9
McLeod gauge	18
Mills, F. P.	4, 14
Mine Rescue Apparatus Research Committee——First Report	4, 30
—Second Report	1, 3, 25
Necks of vacuum flasks	12, 15
—evaporation due to	12, 23
—conduction of heat down	22
Newcastle rescue station	2, 7, 14
Nitrogen—liquid	2

Digitized by Google

Digitized by Google